1994 FEDERAL RADIONAVIGATION PLAN

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Letter of Promulgation

This letter promulgates the eighth edition of the Federal Radionavigation Plan, which was prepared jointly by the Departments of Defense and Transportation. It supersedes the 1992 Federal Radionavigation Plan.

The Federal Radionavigation Plan is published to provide information on the management of those Federally provided radionavigation systems used by both the military and civil sectors. It supports the planning, programming and implementing of air, marine, land and space navigation systems to meet the requirements shown in the President's budget submission to Congress. This plan is the official source of radionavigation policy and planning for the Federal Government, and has been prepared with the assistance of other Government agencies. The Federal Radionavigation Plan is revised biennially. Your suggestions for the improvement of future editions are welcomed.

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Secretary of Defense

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13. ABSTRACT (Maximum 200 words)

The Federal Radionavigation Plan (FRP) delineates policies and plans for radionavigation services provided by the U.S. Government to ensure efficient use of resources and full protection of national interests. Developed jointly by the U.S. Departments of Defense and Transportation, the FRP sets forth the Federal interagency approach to the implementation and operation of radionavigation systems.

The FRP is updated biennially. This eigth edition describes respective areas of authority and responsibility, and provides a management structure by which the individual operating agencies will define and meet requirements in a cost-effective manner. Moreover, this edition contains the current policy on the radionavigation systems mix. The constantly changing radionavigation user profile and rapid advancements in systems technology, require that the FRP remain as dynamic as the issues it addresses. This edition of the FRP builds on the foundation laid by previous editions and further develops national plans towards providing an optimum mix of radionavigation systems for the foreseeable future.

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Preface

The Department of Defense (DOD) and the Department of Transportation (DOT) have developed the eighth edition of the Federal Radionavigation Plan (FRP) to ensure full protection of national interests and efficient use of resources. The plan sets forth the Federal interagency approach to the implementation and operation of Federally provided, common-use (civil and military) radionavigation systems.

The FRP is a review of existing and planned radionavigation systems used in air, space, land, and marine navigation and for purposes other than navigation in terms of user requirements and current status. The FRP contents reflect DOD responsibility for national security, as well as DOT responsibilities for public safety and transportation economy.

The plan is updated biennially. The established DOD/DOT interagency management approach allows continuing control and review of U.S. radionavigation systems. Your inputs for the next edition of this plan are welcome. Interested parties and advisory groups from the private sector are invited to submit their inputs to the Chairman of the DOT Positioning and Navigation (POS/NAV) Working Group (Attn: OST/P-7), Department of Transportation, Office of the Assistant Secretary for Transportation Policy, Washington, DC 20590.

Public radionavigation user conferences that will provide radionavigation system users the opportunity to comment on this document are planned to be held in late 1995 or early 1996.

Table of Contents

List of Figures

List of Tables

Executive Summary

The Federal Radionavigation Plan (FRP) delineates policies and plans for Federally provided radionavigation services. It also recognizes that the existence of privately operated radiodetermination systems may impact future government radionavigation planning. This plan describes areas of authority and responsibility and provides a management structure by which the individual operating agencies can define and meet radionavigation requirements in a cost-effective manner. It is the official source of radionavigation policy and planning for the Federal Government. This edition of the FRP updates and replaces the 1992 FRP and incorporates common-use radionavigation systems (i.e., systems used by both civil and military sectors) covered in the Department of Defense (DOD) Chairman, Joint Chiefs of Staff (CJCS) Master Navigation Plan (MNP). The MNP covers many radionavigation systems used exclusively by the military, and has not been superseded by the FRP.

This document describes the various phases of navigation and other applications of radionavigation services, and provides current and anticipated requirements for each. As requirements change, radionavigation systems may be added or deleted in subsequent revisions to this plan.

The FRP covers common-use, Federally operated systems. These systems are sometimes used in combination or with other systems. Privately operated systems are recognized in the interest of providing a complete picture of U.S. radionavigation.

The systems covered in this plan are:

- GPS
- Augmentations to GPS
- Loran-C

- Omega
- VOR andVOR/DMIE
- TACAN
- ILS
- MLS
- Transit
- Radiobeacons
- Vessel Traffic Services

Augmentations to GPS, such as differential GPS (DGPS), are enhancements to the GPS system. Because of their unique characteristics, these augmented systems are addressed separately in this document. Vessel Traffic Services (VTS) are also discussed, because DGPS is an essential component of the system being installed at Valdez, Alaska, and has the potential for application in future VTS.

A major goal of DOD and the Department of Transportation (DOT) is to select a mix of these common-use (civil and military) systems which meets diverse user requirements for accuracy, reliability, availability, integrity, coverage, operational utility, and cost; provides adequate capability for future growth; and eliminates unnecessary duplication of services. Selecting a future radionavigation systems mix is a complex task, since user requirements vary widely and change with time. While all users require services that are safe, readily available and easy to use, military requirements stress unique defense capabilities, such as performance under intentional interference, operations in high-performance vehicles, worldwide coverage, and operational capability in severe environmental conditions. Cost remains a major consideration which must be balanced with a needed operational capability.

Navigation requirements range from those for small single-engine aircraft or small vessels, which are cost-sensitive and may require only minimal capability, to those for highly sophisticated users, such as airlines or large vessel operators, to whom accuracy, flexibility, and availability may be more important than initial cost. The selection of an optimum mix to satisfy user needs, while holding the number of systems and costs to a minimum, involves complex operational, technical, institutional, international and economic trade-offs. This plan establishes a means to address user inputs and questions, and arrive at an optimum mix determination. This edition of the FRP builds on the foundation laid by previous editions and further develops national plans toward providing an optimum mix of radionavigation systems. The constantly changing radionavigation user profile and rapid advancements in systems technology require that the FRP remain as dynamic as the issues it addresses. This issue of the FRP contains the current policy on the radionavigation systems mix.

This document is composed of the following sections:

Section 1 - Introduction to the Federal Radionavigation Plan: Delineates the purpose, scope and objectives of the plan, presents the DOD and DOT authority and responsibilities for providing radionavigation services, and describes the DOD and DOT policies and plans for the radionavigation system mix.

Section 2 - Radionavigation System User Requirements: Provides civil and military requirements for air, space, land, and marine navigation, and positioning and timing applications.

Section 3 - Radionavigation System Use: Describes how the various radionavigation systems are used in meeting civil requirements, and the status and plans for each system.

Section 4 - Radionavigation System Research, Engineering and Development Summary: Presents the research, engineering, and development efforts planned and conducted by DOT, DOD, and other Federal organizations.

Appendix A - System Descriptions: Describes present and planned navigation systems in terms of ten major parameters: signal characteristics, accuracy, availability, coverage, reliability, fix rate, fix dimensions, system capacity, ambiguity, and integrity.

Appendix B - Reference Systems: Discusses geodetic datums and the reference systems based upon them.

Appendix C - Definitions

Appendix D - Glossary

Index

1

Introduction to the Federal Radionavigation Plan

This section describes the background, purpose, and scope of the Federal Radionavigation Plan (FRP). It summarizes the events leading to the preparation of this document and the national objectives for coordinating the planning of radionavigation services. The remaining contents of Section 1 set forth national policy, radionavigation authority and responsibility, and radionavigation system planning.

1.1 Background

The first edition of the FRP was released in 1980 as part of a Presidential Report to Congress, prepared in response to the International Maritime Satellite (INMARSAT) Act of 1978. It marked the first time that a joint Department of Transportation (DOT) and Department of Defense (DOD) plan for common-use (both civil and military) systems had been developed. Now, this biennially-updated plan serves as the planning and policy document for all present and future Federally provided common-use radionavigation systems. This edition also reflects input obtained at the radionavigation user conferences held in 1993.

The 1979 DOD/DOT Interagency Agreement for joint radionavigation planning, as well as for the development and publication of the FRP, was renewed in 1990. This agreement recognizes the need to coordinate all Federal radionavigation system planning and to attempt, wherever consistent with operational requirements, to utilize common systems. A memorandum of agreement between the DOD and DOT on the civil use of the Global Positioning System (GPS) signed in January 1993 established policies and procedures to ensure an effective working relationship between the two Departments regarding the civil use of GPS.

Since the publication of the first edition of the FRP, there have been significant changes in the radionavigation environment. A Joint DOD/DOT Task Force on GPS report to the Secretaries of Defense and Transportation, dated December, 1993, recommended the creation of a GPS Executive Board, composed of an Assistant Secretary from each Department. The purpose of the Board was to resolve conflicts arising from joint civil and military use of GPS. The report also recommended assignment of radionavigation policy and planning responsibilities to a DOT Assistant Secretary and establishment of a DOT Positioning and Navigation (POS/NAV) Executive Committee within DOT to mirror a similar organization within DOD. The report was accepted by both Secretaries. The new POS/NAV management structure is shown in Figure 1-1. In a memorandum dated May 18, 1994, the Secretary of Transportation transferred the radionavigation oversight function to the Assistant Secretary for Transportation Policy (OST/P).

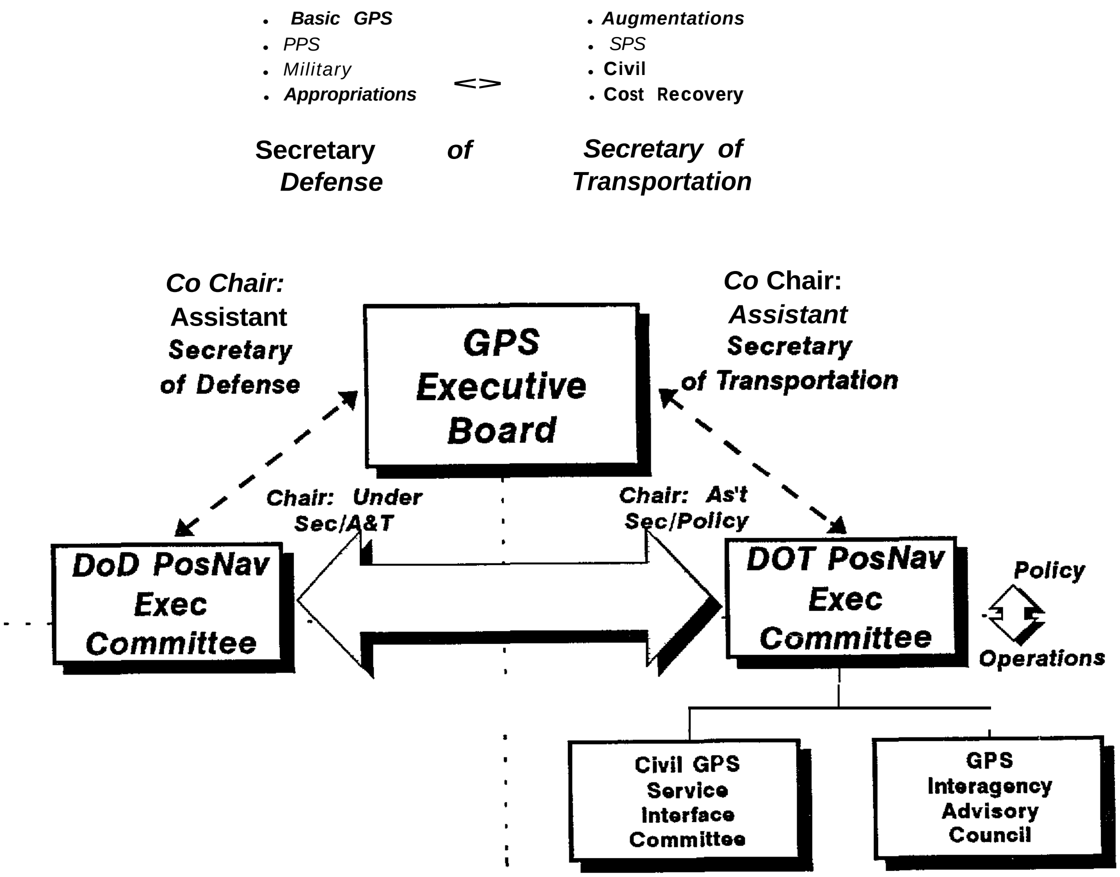


Figure 1-1. Joint DOD/DOT POS/NAV Management Structure

Although GPS is a principal driving force in the FRP, other external factors such as breakthroughs in technology, reductions in receiver costs, marketplace pressures, and increasing private sector involvement have affected the evolution of the FRP.

In 1990, the FRP began expanded discussions of land uses of radionavigation systems. This was driven primarily by a recognition of the use of systems such as GPS and Loran-C in land transportation applications. The 1994 FRP continues to update discussions on land applications, including the extensive use of radionavigation systems for positioning, surveying, timing, weather research, and many other applications.

The Federal Government holds open meetings every two years to provide the user community with the opportunity to comment on Federal radionavigation system policies and plans. The 1993 radionavigation user conferences were held on November 9-10 in Washington, D.C.; on November 30 in Columbus, Ohio; and on December 2 in Seattle, Washington.

Comments from the users indicated strong support for use of the GPS by the civil community. There appears to be a preference among users for some level of nationwide standardization of differential GPS (DGPS) services to avoid proliferation of different data formats and transmission media. There is also a strong trend of increasing use of GPS for non-navigation purposes, such as positioning, surveying, and timing, among government agencies and private industry.

Representatives from the Loran-C and Omega communities recommended that promoting the competitiveness of the U.S. radionavigation manufacturers should be a stated Federal policy. Important steps in fulfilling this objective include close cooperation between manufacturers and government.

The air transport industry strongly supports a near-term transition to GPS-based navigation and landing systems in the National Airspace System (NAS). The general aviation community and state aviation authorities support timely, well-proven implementation of GPS and Loran-C approaches to meet the need for more instrument approaches at airports currently lacking such capability. The aviation community also desired clarification of the Microwave Landing System (MLS) policy.

The United States Coast Guard (USCG) stated that the planned phase-out periods for Loran-C and Omega are being revisited due to the expected high user equipage with GPS. These statements resulted in numerous requests from the user community to retain the transition periods that are stated for these two systems in the 1992 FRP.

Many users stated concerns with having to rely on one navigation system and felt that safety dictated the availability of alternative systems.

The need to consolidate and reduce the number of systems is a major objective of DOD and DOT. The constantly changing radionavigation user profile and rapid advancements in systems technology require that the FRP remain as dynamic as the issues addressed. The current DOD/DOT policy on the radionavigation systems mix is presented in Section 1.6.

1.2 Purpose

The purpose of the FRP is to:

- Present an integrated Federal policy and plan for all common-use civil and military radionavigation systems.
- Provide a document for specifying radionavigation requirements and addressing common-use systems and applications.
- Outline an approach for consolidating radionavigation systems.
- Provide government radionavigation system planning information and schedules.
- Define and clarify new or unresolved common-use radionavigation system issues.
- Provide a focal point for user input.

1.3 Scope

This plan covers Federally provided, common-use radionavigation systems, acknowledging that these systems can be used for other purposes. It also briefly addresses privately owned systems such as Radar Transponder Beacons (RACONs), and others that interface with or impact Federally provided systems. The plan does not include systems which mainly perform surveillance and communication functions.

The major systems subject to the planning process described in this FRP are:

- GPS
- Augmentations to GPS
- Loran-C
- Omega
- VOR and VOR/DME
- TACAN
- ILS
- MLS
- Transit
- Radiobeacons
- VTS

Augmentations to GPS, such as DGPS, are enhancements to the GPS system. Because of their unique characteristics, these augmented systems are addressed separately in this document.

Transit, a satellite-based radiodetermination system, is discussed because of its use in marine navigation.

Vessel Traffic Services (VTS) are also discussed, because DGPS is an essential component of the system being installed at Valdez, Alaska, and has the potential for use in future VTS.

1.4 Objectives

The radionavigation policy of the United States has evolved through statute, usage, and in the interest of national defense and public safety. The objectives of U.S. Government radionavigation system policy are to:

- Support national security.
- Provide safety of travel and promote environmental protection.
- Promote efficient transportation.
- Support national positioning and timing requirements.

1.5 Policies and Practices

The following U.S. Government policies and practices support the above objectives:

a. Implementation and operation of radio aids to navigation. Services which contribute to safe, expeditious, and economic air, land and maritime commerce and which support United States national security interests are provided.

b. Installation and operation of radionavigation systems in accordance with international agreements.

c. Avoidance of unnecessary duplication of radionavigation systems and services. The highest degree of commonality and system utility between military and civil users is sought through early consideration of mutual requirements.

d. Recognition of electromagnetic spectrum requirements in the planning and management of radionavigation systems.

e. Promotion of transportation safety and environmental protection by requiring certain vessels and aircraft to be fitted with radionavigation equipment as a condition for operating in the controlled airspace or navigable waters of the United States.

f. Direction to ensure that radionavigation services available to civil users meet projected demand, performance, safety, and environmental protection requirements considering economic constraints on radionavigation system providers and users.

g. Evaluation of domestic and foreign radio aids to navigation, with support for the development of those systems having the potential to meet unfulfilled operational requirements; those offering major economic advantages over existing systems; and those providing significant benefits in the national interest.

h. Establishment of a suitable transition period based on user equipage and acceptance, budgetary considerations, and the public interest.

i. Promotion of international exchange of scientific and technical information concerning radionavigation aids.

j. Guidance and assistance in siting, testing, evaluating, and operating non-Federal and private radio aids to meet unique aviation requirements.

k. Promotion of national and international standardization of civil and military radionavigation aids.

l. Establishment, maintenance, and dissemination of system and signal standards and specifications.

m. Development, implementation, and operation of the minimum special radionavigation aids and services for military operations.

n. Operation of common-use radionavigation systems as long as the United States and its allies accrue greater military benefit than potential adversaries. Operating agencies may cease operations or change characteristics and signal formats of radionavigation systems during a dire national emergency, as declared by the National Command Authority (NCA).

o. Provision of the GPS Standard Positioning Service (SPS) for continuous, worldwide civil use at the highest level of accuracy consistent with U.S. national security interests.

p. Implementation of the Global Positioning System as the world's standard in the air, on land, and over water.

q. Enhancement of GPS for civil applications.

r. Equipping of military vehicles, as appropriate, to satisfy civil aviation and maritime navigation safety requirements. However, the primary concern will be that U.S. military vehicles and users are equipped with navigation systems which best satisfy mission requirements. Standardization, although important, may be disregarded when unique military systems provide the capability to operate safely without reference to civil radionavigation systems.

s. Establishment of mechanisms, where practical, for users of Federally provided radionavigation systems to bear their fair share of the costs (except for direct charges for basic GPS signals) for development, procurement, operation, and maintenance of these systems.

t. Provision, through DOD/DOT interagency agreements, of comprehensive management for all Federally provided common-use radionavigation systems.

u. Ensuring, in accordance with the national policy found in OMB Circular A-76, that the private sector is considered in the design, development, installation, operation, and maintenance of all equipment and systems required to provide common-use radionavigation aids in support of this FRP (within the constraints of national security).

1.6 DOD/DOT Policy on the Radionavigation System Mix

The Department of Transportation is responsible under 49 United States Code (U.S.C.) 301 for ensuring safe and efficient transportation. Radionavigation systems play an important role in carrying out this responsibility. The two main elements within DOT that operate radionavigation systems are the USCG and the Federal Aviation Administration (FAA). The Assistant Secretary for Transportation Policy (OST/P) is responsible for coordinating radionavigation planning within DOT and with other civil Federal elements.

The USCG provides U.S. aids to navigation for safe and efficient marine navigation. The FAA has the responsibility for the development and implementation of radionavigation systems to meet the needs for safe and efficient air navigation, as well as for control of all civil and military aviation, except for military aviation needs peculiar to warfare and primarily of military concern. The FAA also has the responsibility to operate aids to air navigation required by international treaties.

Other elements within DOT participate in radionavigation planning. These elements include the St. Lawrence Seaway Development Corporation (SLSDC), the Maritime Administration (MARAD), the Office of Commercial Space Transportation (OCST), the Federal Highway Administration (FI-IWA), the Federal Railroad Administration (FRA), the National Highway Traffic Safety Administration (NHTSA), the Federal Transit Administration (FTA), the Research and Special Programs Administration (RSPA), the Bureau of Transportation Statistics (BTS), and the Intelligent Transportation Systems Joint Program Office (ITS-JPO).

The Department of Defense is responsible for developing, testing, evaluating, implementing, operating, and maintaining aids to navigation and user equipment required for national defense and ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigational capabilities.

All common-use systems operating or planned were considered in developing the policy on the mix of Federally provided radionavigation systems. The statement that follows is the DOD/DOT radionavigation policy.

Federal Policy and Plans for the Future Radionavigation Systems Mix (1994 Federal Radionavigation Plan)

Purpose: This statement sets forth the policy and plans for Federally provided radionavigation systems.

Objectives: The Federal Government operates radionavigation systems as one of the necessary elements to enable safe transportation and encourage commerce within the United States. It is a goal of the Government to provide this service in a cost-effective manner. In order to meet both civil and military radionavigation needs, the Government has established a series of radionavigation systems over a period of years. Each system utilizes the latest technology available at the time of introduction to meet existing or unfulfilled needs. This statement addresses the conditions under which each system will be part of the Federal radionavigation systems mix.

The Department of Defense (DOD) has deployed a new dual-use (civil and military) radionavigation system, the Global Positioning System (GPS). This system meets or exceeds the accuracy and coverage of many other radionavigation systems. Consequently, as the full civil potential of GPS is realized, the Federal Government expects to phase out radionavigation systems that no longer will be required.

Decisions to discontinue Federal operation of existing systems will depend upon many factors including: (a) resolution of GPS accuracy, coverage, integrity, financial, and institutional issues; (b) determination that the resulting systems mix meets civil and military needs currently met by existing systems; (c) availability of civil user equipment at economically acceptable prices; (d) establishment of a suitable transition period based on user equipage and acceptance, budgetary considerations, and the public interest, and (e) resolution of international commitments.

Although radionavigation systems are established primarily for safety of transportation, they also provide significant benefits to positioning and timing users. In recognition of this, any changes to Federal operation of radionavigation systems will consider these needs.

Radionavigation systems operated by the U.S. Government will be available subject to direction by the National Command Authority (NCA) because of a real or potential threat of war or impairment to national security. Radionavigation systems will be operated as long as the U.S. and its allies accrue greater military benefit than do adversaries. Operating agencies may cease operations or change characteristics and signal formats of radionavigation systems during a dire national emergency. All licensed communication links, including those used to transmit differential GPS corrections and other GPS augmentations, are also subject to the direction of the NCA.

Individual System Plans:

GPS: GPS, a satellite-based radionavigation system operated by the DOD and jointly managed by the DOD and the DOT, provides two levels of service-a Standard Positioning Service (SPS) and a Precise Positioning Service (PPS). SPS will be available to all users on a continuous, worldwide basis, for the foreseeable future, free of any direct user charge. The specific capabilities provided by SPS are established by DOD and DOT and are published in the Global Positioning System Standard Positioning Service Signal Specification, available through the U.S. Coast Guard (USCG) Navigation Information Service. PPS, the most accurate service directly available from GPS without augmentation, is available to U.S. and allied military and U.S. Federal Government users. Limited non-Federal Government, civil use of PPS, both domestic and foreign, will be considered upon request and authorized on a case-by-case basis, provided:

- It is in the U.S. national interest to do so.
- Specific GPS security requirements can be met by the applicant.
- A reasonable alternative to the use of PPS is not available.

Augmentations to GPS: When augmented to satisfy civil requirements for accuracy, coverage, and integrity, GPS will be the primary Federally provided radionavigation system for the foreseeable future.

In December 1993, the Joint DOD/DOT Task Force on GPS recommended a study of all augmented GPS services under deployment or development to determine the optimum integrated approach to providing augmented GPS services. In response to this recommendation, DOT and DOD undertook a study in 1994 to evaluate the capabilities of various means of augmenting GPS and to determine the optimum integrated system for meeting the requirements of Federal land, marine, aviation, and space users. Recommendations from this study are currently under evaluation.

Augmentations to GPS are enhancements of the basic GPS system to meet unique requirements. Augmentations to GPS fall into three categories: 1) differential GPS (DGPS), 2) GPS integrity broadcasts (GIB), and 3) additional inputs from non-GPS navigation systems, equipment, or techniques.

DOD and DOT will not constrain the use of SPS-based differential GPS services as long as applicable U.S. statutes and international agreements are adhered to.

Maritime DGPS: The USCG is establishing DGPS service for the harbor and harbor approach phase of maritime navigation, as well as for navigation on the Great Lakes and western rivers. Maritime DGPS will use fixed GPS reference stations which will broadcast pseudo-range corrections using maritime radiobeacons. The USCG DGPS system is expected to provide radionavigation accuracy better than 10 meters (2 drms) for U.S. harbor and harbor approach areas by 1996. Until the DGPS service is declared operational by the USCG, users are cautioned that signal availability and accuracy are subject to change due to testing of this developing service and the uncertain reliability of prototype equipment.

Aeronautical Augmentations to GPS/SPS: The Federal Aviation Administration (FAA), in cooperation with other DOT organizations and DOD, is planning to augment the GPS/SPS with both a wide area and a local area system. The Wide Area Augmentation System (WAAS) can provide the required accuracy, integrity, and availability to be the primary means of navigation for all phases of flight from en route to Category I approaches. The Local Area Augmentation System (LAAS) may provide the required accuracy, integrity, and availability for Category II and Category III precision approaches. The Special Category I (SCAT-I) system will provide the required Category I service for private users.

Loran-C:

Loran-C provides radionavigation coverage for maritime navigation in U.S. coastal areas. It provides navigation, location, and timing services for both civil and military air, land and marine users. Loran-C is approved as a supplemental air navigation system and also serves a large number of users that operate under Visual Flight Rules (VFR). The Loran-C system serves the 48 conterminous states, their coastal areas, and certain parts of Alaska. The system is expected to remain part of the radionavigation mix until the year 2000, to accommodate the transition to GPS. Continued operation after that date will depend on validating requirements for Loran-C that cannot be met by GPS or another system.

The DOD requirement for the Loran-C system ended December 3 1, 1994. Operations conducted by the USCG at overseas stations were phased out by the end of 1994.

Omega: Omega provides global radionavigation coverage and primarily serves maritime, aviation, and weather users. The U.S. operates Omega under bilateral agreements with six partner nations (Norway, Liberia, France, Argentina, Australia, and Japan). The U.S. expects to continue Omega operations until September 30, 1997, to accommodate the transition of civil aviation users to GPS. Continued operation after that date will depend upon validating requirements for Omega that cannot be met by GPS or another system.

The DOD requirement ended December 3 1,1994; however, limited Service use is expected while the system remains operational.

VOR/DME: VOR/DME provides users with the primary means of air navigation in the National Airspace System (NAS). VOR/DME will remain the primary means of navigation for the en route through nonprecision approach phases of flight until GPS is approved to meet the Required Navigation Performance (RNP) for these phases of flight and the GPS WAAS is approved as a primary means of navigation. The current International Civil Aviation Organization (ICAO) protection date for VOR/DME is January 1, 1998. The phaseout of VOR/DME from the NAS is expected to begin in 2005 and to be complete by 2010.

The DOD requirement for and use of VOR/DME will terminate when aircraft are properly integrated with GPS and when GPS is certified by the DOD to meet RNP for national and international controlled airspace. The target date is the year 2000.

TACAN: TACAN is the military counterpart of VOR/DME. The DOD requirement for and use of land-based TACAN will terminate when aircraft are properly integrated with GPS and when GPS is certified by the DOD to meet RNP in national and international controlled airspace. The target date to begin TACAN phaseout is the year 2000. Individual proposals for decommissioning of FAA-maintained TACANs prior to this date will be assessed and approved on a case-by-case basis after an evaluation of operational requirements.

Precision Landing Systems:

The Instrument Landing System (ILS) serves as the standard for civil precision approach systems in the U.S. and abroad. It will remain the standard for Category I precision approaches until replaced by GPS-based service. WAAS Category I approaches are expected to be introduced into the NAS in 1997 and to become a primary service in 2001. Dual ILS and WAAS service will be provided for a transition period to allow users to equip with WAAS receivers and to become comfortable with its service. The phaseout of Category I ILS is then expected to begin in 2005 and to be complete by 2010.

For Category II and III precision approaches, test results show that a GPS-based system promises to more-affordably deliver this level of service than ILS. Based on these results, GPS-based Category II/III systems are anticipated to be introduced into the NAS by 2001, collocated at existing ILS Category II/III sites. The phaseout of Category II/III ILS from the NAS is then expected to begin in 2005 and to be complete by 2010.

Previous analysis done by the international community and in the U.S. resulted in ICAO selecting the Microwave Landing System (MLS) as the new international standard for precision approach systems. This selection was made before GPS was operational and before its potential to deliver precision approaches was explored. The U.S. is now working with ICAO Member States to change this guidance, and expects a revision to the current recommendation which calls for the phaseout of ILS in favor of MLS. The U.S. will continue to promote the international acceptance and implementation of GPS for navigation in all phases of flight. The FAA has terminated the development of MLS based on favorable GPS test results and budgetary constraints. The U.S. does not anticipate installing additional MLS equipment in the NAS, but could purchase systems on the open market for Category II/III operations if the need should arise in the future.

Transit:

Transit is a satellite-based positioning system operated by DOD. Transit will terminate and system operation will be discontinued no later than December 31,1996.

Radiobeacons: Maritime and aeronautical radiobeacons serve the civilian user community with low-cost navigation. Selected maritime radiobeacons are being modified to carry differential GPS correction signals. This may cause these maritime radiobeacons to be unusable by certain aeronautical receivers. Maritime radiobeacons not used for DGPS may be phased out by the year 2000. Many of the functions of the aeronautical nondirectional beacon (NDB) are now being provided by GPS. Many NDBs that provide redundant service will begin to be phased out in the year 2000 with most NDBs expected to be decommissioned by 2005.

1.7 DOD Responsibilities

DOD is responsible for developing, testing, evaluating, operating, and maintaining aids to navigation and user equipment required for national defense, and for ensuring that military vehicles operating in consonance with civil vehicles have the necessary navigational capabilities. Specific DOD responsibilities are to:

a. Define performance requirements applicable to military mission needs.

b. Design, develop, and evaluate systems and equipment to ensure cost-effective performance.

c. Maintain liaison with other government research and development activities affecting military radionavigation systems.

d. Develop forecasts and analyses as needed to support the requirements for future military missions.

e. Develop plans, activities, and goals related to military mission needs.

f. Define and acquire the necessary resources to accomplish mission requirements.

g- Identify special military route and airspace requirements.

h. Foster standardization and interoperability of systems with North Atlantic Treaty Organization (NATO) and other friendly countries.

i. Operate and maintain ground radionavigation aids as part of the NAS when such activity is economically beneficial and specifically agreed to by the appropriate DOD and DOT agencies.

j. Derive and maintain astronomical and atomic standards of time and time interval, and to disseminate these data.

The Defense Mapping Agency (DMA) is responsible for military mapping, charting, and geodesy aspects of navigation, including geodetic surveys, accuracy determination, and positioning. Within DOD, DMA acts as the primary point of contact with the civil community on matters relating to geodetic uses of navigation systems. Unclassified data prepared by the DMA are available to the civil sector.

The U.S. Naval Observatory (USNO) is responsible for determining the positions and motions of celestial bodies, the motions of the Earth and precise time; for providing the astronomical and timing data required by the Navy and other components of DOD and the general public for navigation, precise positioning, and command, control and communications; and for making these data available to other government agencies and to the general public.

The USN0 role as the nation's time standard was stated most recently in the National Defense Authorization Act FY92 and 93 Report, page 50. "The Department of the Navy serves as the country's official time keeper, with the master clock facility at the Washington Naval Observatory."

DOD carries out its responsibilities for radionavigation coordination through the internal management structure shown in Figure l-2. The two major parts of the structure represent the administrative and the operational chains of command reporting to the Secretary of Defense.

1.7.1 Operational Management

The President or the Secretary of Defense, with the approval of the President, is the National Command Authority. The Chairman, Joint Chiefs of Staff (CJCS), supported by the Joint Staff, is the primary military advisor to the National Command Authority. The Service Chiefs provide guidance to their military departments in the preparation of their respective detailed navigation plans. The JCS are aware of operational navigation requirements and capabilities of the Unified Commands and the Services, and are responsible for the development, approval, and dissemination of the CJCS Master Navigation Plan (MNP).

The MNP is the official navigation policy and planning document of the CJCS. It is a coordinated navigation system plan which addresses operational defense requirements.

The following organizations also perform navigation management functions:

The Deputy Director for Defense-Wide Command, Control and Communications Support, Joint Staff, is responsible for:

- Analysis, evaluation, and monitoring of navigation system planning and operations.
- General navigation matters and the CJCS MNP.

The Commanders of the Unified Commands perform navigation functions similar to those of the JCS. They develop navigation requirements as necessary for contingency plans and JCS exercises that require navigation resources external to that command. They are also responsible for review and compliance with the CJCS MNP.

7.7.2 Administrative Munagemenf

Three permanent organizations provide radionavigation planning and management support to the Under Secretary of Defense for Acquisition and Technology (USD/A&T). These organizations are the POS/NAV Executive Committee; the POS/NAV Working Group; and the Military Departments/ Service Staffs. Brief descriptions are provided below.

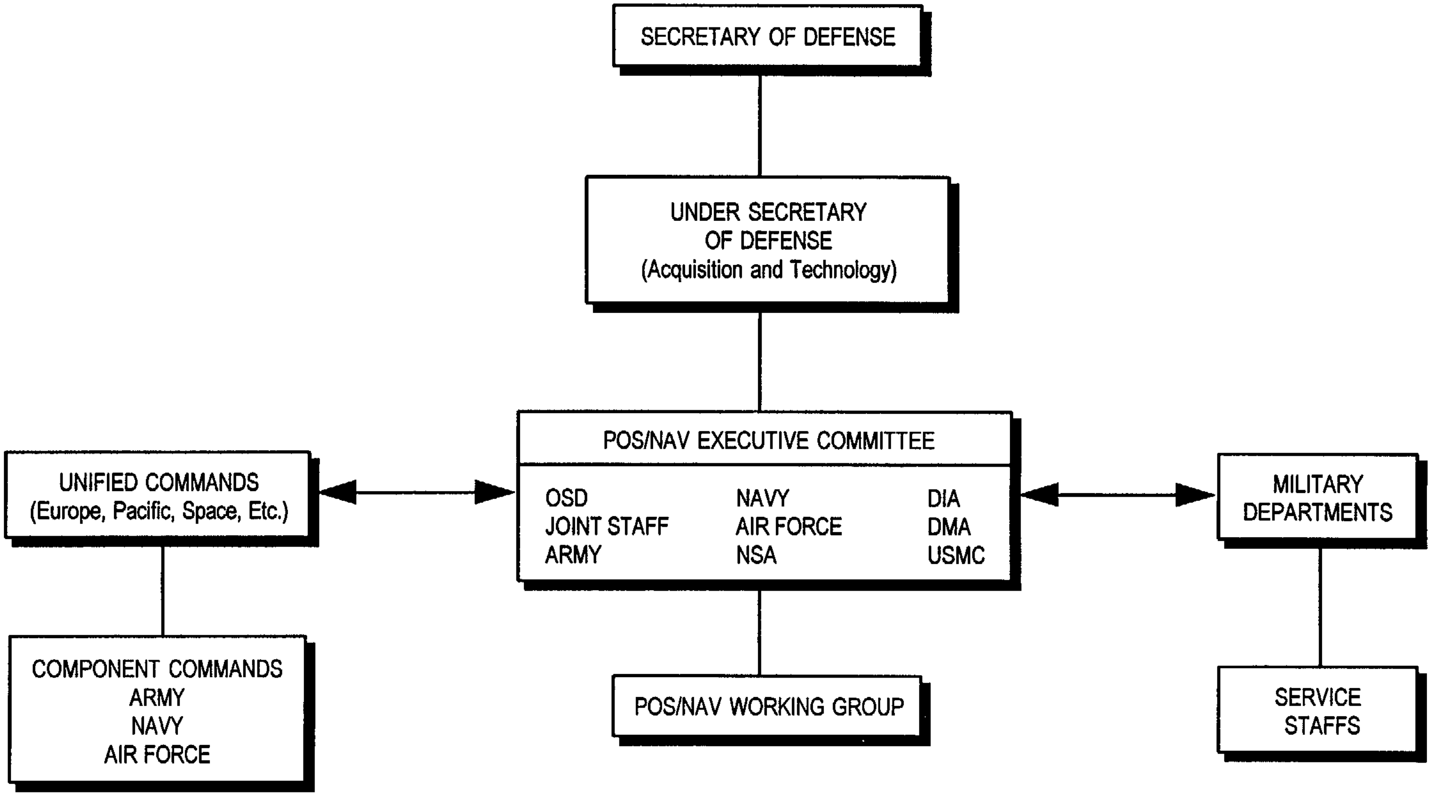


Figure 1-2. DOD Navigation Management Structure

The DOD POS/NAV Executive Committee is the DOD focal point and forum for all DOD POS/NAV matters. It provides overall management supervision and decision processes, including intelligence requirements (in coordination with the Defense Intelligence Agency and the National Security Agency). The Executive Committee contributes to the development of the FRP and coordinates with the DOT POS/NAV Executive Committee.

The DOD POS/NAV Working Group supports the Executive Committee in carrying out its responsibilities. It is composed of representatives from the same DOD components as the Executive Committee. The Working Group identifies and analyzes problem areas and issues, participates with the DOT POS/NAV Working Group in the revision of the FRP, and submits recommendations to the Executive Committee.

The Military Departments/Service Staffs are responsible for participating in the development, dissemination and implementation of the CJCS MNP and for managing the development, deployment, operation, and support of designated navigation systems.

A special committee, the GPS Phase-In Steering Committee, has been established to guide the development and implementation of the policies, procedures, support requirements, and other actions necessary to effectively phase GPS into the military operational forces.

1.8 DOT Responsibilities

DOT is the primary government provider of aids to navigation used by the civil community and of certain systems used by the military. It is responsible for the preparation and promulgation of radionavigation plans in the civilian sector of the United States. DOT carries out its responsibilities for civil radionavigation systems planning through the internal management structure shown in Figure l-3. The structure was originally established by DOT Order 1120.32 (April 27, 1979) and revised by DOT Order 1120.32C (October 11, 1994) for the following purposes:

a. To provide an organizational structure that will facilitate the coordination of policy recommendations and integrated planning regarding navigation and positioning among the operating elements of DOT, to help assure the most efficient implementation of these policies and plans, and to help ensure the most effective use of resources of the DOT operating elements (i.e., help avoid duplication of effort).

b. To provide a management level body which can, on a continuing basis, facilitate coordination of navigation and positioning planning on a multimodal basis within DOT, and to serve as a focal point for recommendations on which DOT navigation and positioning policies and plans can be formulated.

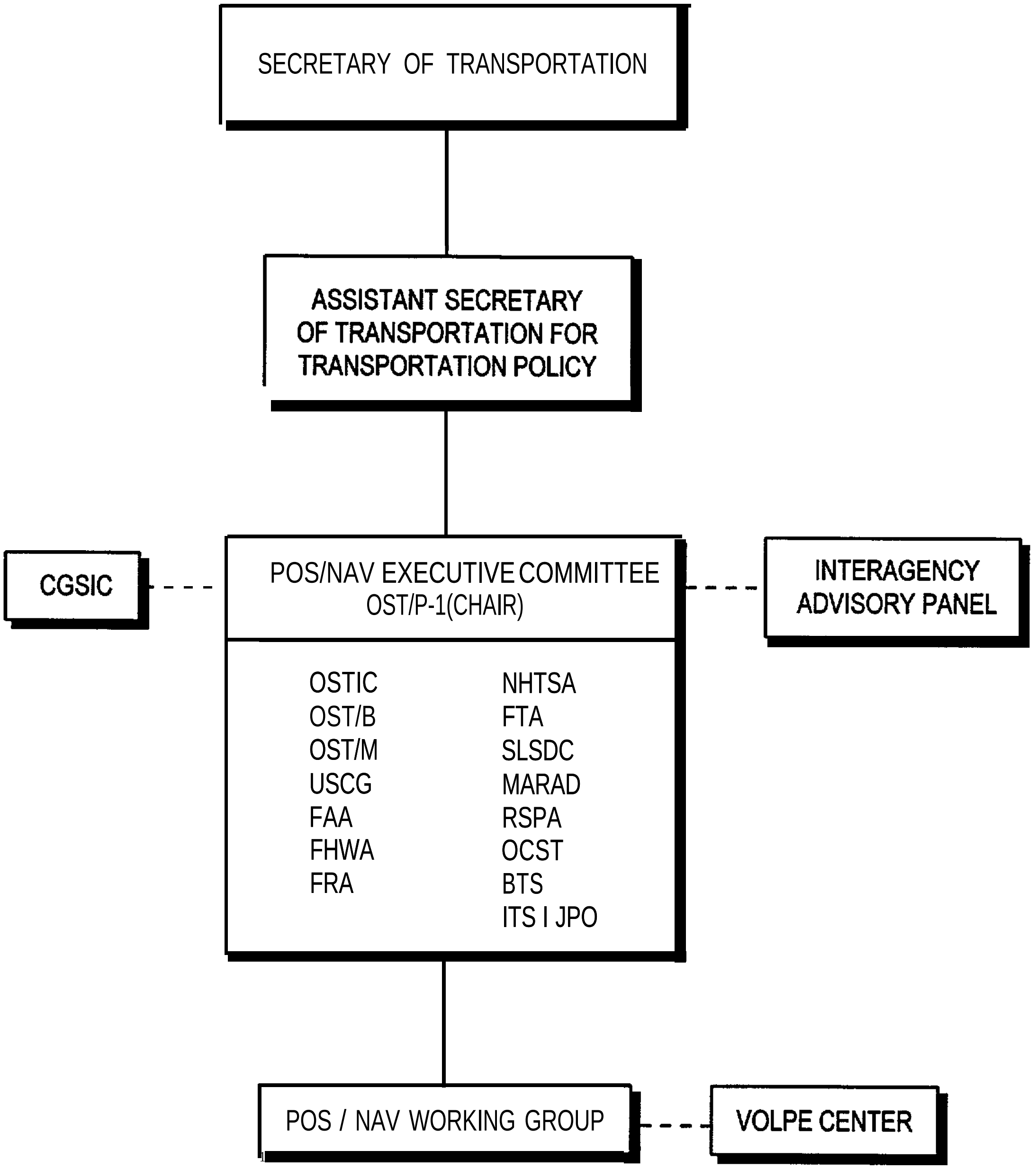


Figure I-3. DOT Navigation Management Structure

c. To assure that the Secretary of Transportation receives consolidated information; and to provide the means to obtain a coordinated high-level review of proposed navigation and positioning policies and plans.

d. To establish a planning framework wherein the DOT operating elements are allowed maximum latitude for navigation and positioning system research, development, and implementation, consistent with OST/P policy guidance and the need to avoid duplication of effort.

e. To provide the technical resources and appropriate management structure to supplement navigation and positioning planning, implementation, coordination, and decision making of the operating elements.

f. To provide a focal point for obtaining inputs from those elements of DOT which may not have a continuous interest in navigation and positioning issues.

g. To provide a DOT focal point for multimodal or inter-departmental navigation and positioning issues.

h. To provide liaison with DOD.

i. To coordinate DOT activities aimed at promoting international acceptance of U.S. radionavigation systems and supporting U.S. radionavigation and positioning manufacturing and service industries.

The DOT POS/NAV Executive Committee is the top-level management body of the organizational structure. It is chaired by the OST/P, and consists of policy level representatives from the General Counsel's Office (OST/C), the Office of the Assistant Secretary for Budget and Programs (OST/B), the Assistant Secretary for Administration (OST/M), USCG, FAA, FHWA, FRA, NHTSA, FTA, SLSDC, MARAD, RSPA, OCST, BTS, and ITS-JPO. The DOT POS/NAV Executive Committee:

(1) serves as the focal point to formulate coordinated policy recommendations to the Secretary;

(2) provides policy and planning guidance to the Department's operating administrations on navigation and positioning matters;

(3) attempts to resolve any multimodal navigation and positioning issues that cannot be resolved by the POS/NAV Working Group;

(4) is the focal point for coordination with similar committees in other government agencies;

(5) provides unified Departmental comments on the proposed rulemakings of other governmental agencies in regard to radionavigation and positioning and related matters; and

(6) provides guidance to the POS/NAV Working Group.

The POS/NAV Working Group is the staff working core of the organizational structure. It will be chaired by the OST/P Program Manager and will consist of one representative each from OST/C, OST/B, OST/M, USCG, FAA, FHWA, FRA, NHTSA, FTA, SLSDC, MARAD, RSPA, OCST, BTS, the Volpe National Transportation Systems Center (Volpe Center), ITS-JPO, and other DOT element representatives as necessary. Each representative may be assisted by advisors. The Center for Navigation, Volpe Center, also provides technical assistance to the POS/NAV Working Group. The Working Group shall facilitate the coordination of:

(1) navigation and positioning requirements developed by the DOT operating elements;

(2) navigation and positioning plans;

(3) navigation and positioning R&D (research and development) and implementation programs;

(4) DOT navigation and positioning planning with the Department of Defense, the Department of Commerce (DOC), the National Aeronautics and Space Administration (NASA), the Federal Geographic Data Committee (FGDC), and other Federal agencies, as required;

(5) multimodal navigation and positioning issues with other governmental agencies, industry, and user groups, as directed by the POS/NAV Executive Committee; and

(6) Department comments on the proposed rulemakings of other governmental agencies in regard to radionavigation and positioning and related matters.

The operating elements within DOT, as appropriate with their mission, shall:

(1) assess, analyze, and document navigation and positioning requirements;

(2) conduct the necessary research and development on navigation and positioning systems having potential application to their operation;

(3) implement navigation and positioning systems needed to carry out their responsibilities to the public in a cost-effective manner, and participate with other DOT agencies in implementation of common-use systems;

(4) retain existing responsibilities, under policy guidance from OST/P, for direct coordination with DOD on matters related to specific navigation and positioning systems operated by the individual elements of DOT; and

(5) retain existing responsibilities, under policy guidance from OST/P, for international coordination on navigation and positioning matters for their appropriate transportation mode.

The Secretary of Transportation, under 49 U.S.C. 301, has overall leadership responsibility for navigational matters within DOT and promulgates radionavigation plans. Three DOT elements have statutory responsibilities for providing aids to navigation: the USCG, the FAA, and the SLSDC. In addition, several other elements of DOT and NASA have responsibilities and interests which may be satisfied by radionavigation or radiolocation systems.

OST/P coordinates radionavigation issues and planning which affect multiple modes of transportation, including those that are inter-modal in nature. OST/P also interfaces with agencies outside of DOT on non-transportation uses of radionavigation systems.

The USCG defines the need for, and provides, aids to navigation and facilities required for safe and efficient navigation. Section 81 of Title 14, U.S.C. states the following:

"In order to aid navigation and to prevent disasters, collisions, and wrecks of vessels and aircraft, the Coast Guard may establish, maintain, and operate:

(1) aids to maritime navigation required to serve the needs of the armed forces or of the commerce of the United States;

(2) aids to air navigation required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or the Secretary of any department within the Department of Defense and as requested by any of those officials; and

(3) electronic aids to navigation systems (a) required to serve the needs of the armed forces of the United States peculiar to warfare and primarily of military concern as determined by the Secretary of Defense or any department within the Department of Defense; or (b) required to serve the needs of the maritime commerce of the United States; or (c) required to serve the needs of the air commerce of the United States as requested by the Administrator of the Federal Aviation Administration.

These aids to navigation other than electronic aids to navigation systems shall be established and operated only within the United States, the waters above the Continental Shelf, the territories and possessions of the United States, the Trust Territory of the Pacific Islands, and beyond the territorial jurisdiction of the United States at places where naval or military bases of the United States are or may be located. The Coast Guard may establish, maintain, and operate aids to marine navigation under paragraph (1) of this section by contract with any person, public body, or instrumentality."

The FAA has responsibility for development and implementation of radionavigation systems to meet the needs of all civil and military aviation, except for those needs of military agencies which are peculiar to air warfare and primarily of military concern. FAA also has the responsibility to operate aids to air navigation required by international treaties.

MARAD investigates position determination using existing and planned navigation systems, conducts precision navigation experiments, and investigates the application of advanced technologies for navigation and collision avoidance. These efforts are designed to enhance U.S. Merchant Marine efficiency and effectiveness.

The SLSDC has responsibility for assuring safe navigation along the St. Lawrence Seaway. The SLSDC provides navigational aids in U.S. waters in the St. Lawrence River and operates a Vessel Traffic Control System with the St. Lawrence Seaway Authority of Canada.

FHWA, NHTSA, FRA, FTA, and RSPA have the responsibility to conduct research, development, and demonstration projects, including projects on land uses of radiolocation systems. They also assist state and local governments in planning and implementing such systems and issue guidelines concerning their potential use and applications.

The OCST is charged with: (1) promoting, encouraging, and facilitating commercial space transportation by the U.S. private sector; and (2) ensuring public safety with respect to commercial space transportation, operation of launch sites and spaceports by the U.S. private sector, and commercial satellites not otherwise licensed by another Federal agency. Accordingly, OCST is interested in the demand for space launches by providers of satellite-based services including radiodetermination.

NASA supports navigation through the development of technologies for navigating aircraft and spacecraft. NASA is responsible for development of user and ground-based equipment, and is also authorized to demonstrate the capability of military navigational satellite systems for civil aircraft, ship, and spacecraft navigation and position determination.

1.9 DOD/DOT Joint Responsibilities

A Memorandum of Agreement (MOA) between DOD and DOT for radronavigation planning became effective in 1979; it was updated in 1984, 1990, and 1994. This agreement requires coordination between the DOD and DOT internal management structures for navigation planning and establishes a GPS Executive Board chaired by DOD (USD/A&T) and DOT (OST/P). The MOA recognizes that DOD and DOT have joint responsibility to avoid unnecessary overlap or gaps between military and civil radionavigation systems and services. Furthermore, it requires that both military and civil needs be met in a manner cost-effective for the Government and civil user community.

Implicit in this joint responsibility is assurance of civil sector radionavigation readiness for mobilization in national emergencies. The agreement provides that DOD and DOT will jointly:

- Inform each other of the development, evaluation, installation, and operation of radio aids to navigation with existing or potential joint applications.
- Coordinate all major radionavigation planning activities to ensure consistency while meeting diverse navigational requirements.
- Attempt, where consistent with diverse requirements, to utilize common systems, equipment, and procedures.
- Undertake joint programs in the research, development, design, testing, and operation of radionavigation systems.
- Prepare a standard definition of requirements and a joint requirements document (FRP) .
- Assist in informing or consulting with other government agencies involved in navigation system research, development, operation, or use, as necessary.
- Publish a single DOD/DOT FRP to be implemented by internal departmental actions. This plan will be reviewed and updated biennially.

1.10 Determination of Future Radionavigation Systems Mix

Many factors determine the choice of the systems mix to satisfy diverse user requirements. They may be categorized according to operational, technical, economic, institutional and international parameters. System accuracy and coverage are the foremost technical parameters, followed by system availability and reliability. Certain unique parameters, such as anti-jamming performance, apply to military needs.

The current investment in ground and user equipment must also be considered. In some cases, there may be international commitments which must be honored or modified in a fashion mutually agreeable to all parties.

In most cases, current systems were developed to meet distinct and different requirements, and they will be retained until such needs no longer exist or can be met by an acceptable systems mix. This development of systems to meet unique requirements led to the development of multiple radionavigation systems and was the impetus for early radionavigation planning. The first edition of the FRP was published to plan the mix of radionavigation systems and promote an orderly life cycle for them. It described an approach for selecting radionavigation systems to be used in the future. Early editions of the FRP, including the 1984 edition, reflected that approach with minor modifications to the timing of events. By 1986, it became apparent that a final recommendation on the future mix of radionavigation systems was not appropriate and major changes to the timing of system life-cycle events were required. Consequently, it was decided that starting with the 1986 FRP, a current recommendation on the future mix of radionavigation systems would be issued with each edition of the FRP. This current recommendation reflects dynamic radionavigation technology, changing user profiles, and input received at radionavigation user conferences sponsored by DOT and DOD.

1.10.1 Approach to Systems Mix

There are long-term and short-term aspects that need to be addressed in the overall selection process. The long-term goal is to establish, through an integrated DOD and DOT planning and budgeting process, a cost-effective, user-sensitive mix of systems for the post-2000 time frame. As part of this long-term goal, until it can be clearly established which civil requirements being met by existing systems can be met by GPS, there may be a need to improve or expand existing systems. The selection process for the systems to be used in the future allows the flexibility to adopt incremental improvements where justified over the short term. Similarly, the process permits system upgrading and research and development to allow the satisfaction of operational requirements which are not met by existing or planned systems. An example was the combined effort of the USCG and the FAA to provide mid-continent Loran-C coverage.

Figure l-4 shows the process for selecting the Federally provided radionavigation systems to be used in the future. It is recognized that GPS may not meet the needs of all civil users of radionavigation systems. Therefore, some system life cycles are independent of the GPS implementation date. After the ability of GPS to meet user needs has been verified, systems it would potentially replace will be reviewed for future requirements or phase-out.

DOT will maintain liaison with the civil users of radionavigation systems through user conferences or other appropriate means prior to updating the FRP. Input received will become a vital part of the biennial decision-making process on radionavigation system life cycles. This consultation, review, and recommendation cycle will be continued until the ability of GPS to meet civil user needs has been determined. At that time, long-term phase-out or phase-over plans will be considered for those systems replaceable by GPS. During 1995, international, intragovernmental, and user consultations will take place on the future of Federally provided radionavigation systems. Developments in GPS augmentations and the

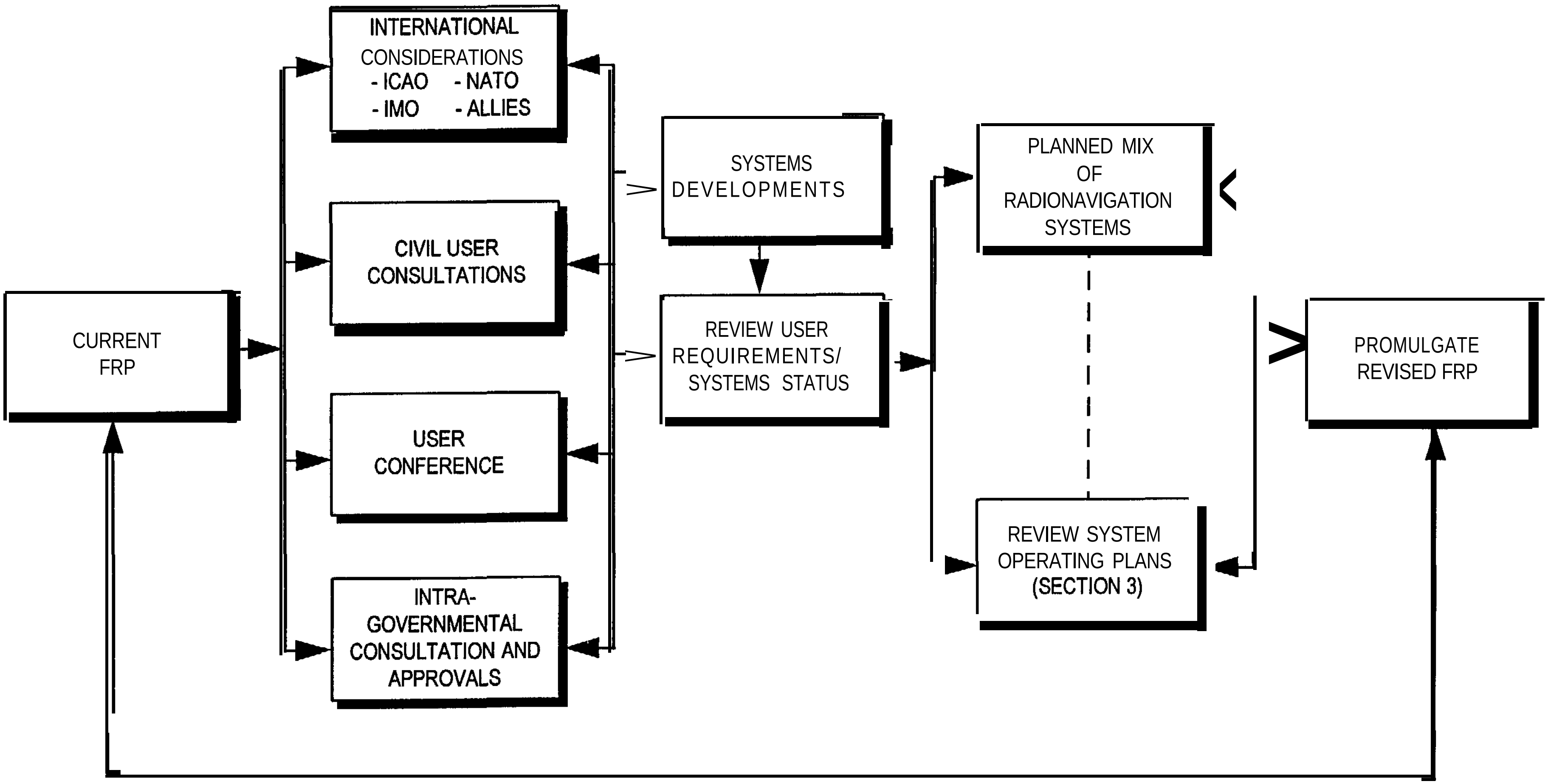


Figure 1-4. DOD/DOT Radionavigation Systems Planning Process

changing needs of civil users will be reviewed. The status and impact of commercial systems will also be considered as a part of this process. In addition, as an alternative to the phasing out of civil radionavigation systems, consideration will be given to the possibility of phasing over their operation to the private sector.

At that point in time when the need or economic justification for a particular system appears to be waning, the Department operating the system will provide notification to the appropriate Federal agencies and to the public, by publication in the Federal Register, of the proposed discontinuance of service and will seek public comment. The Final Rule will be issued only after consideration of all comments received.

For each common-use system, the following process is used to select systems to be part of the future radionavigation systems mix. DOT will evaluate civil requirements for a system including requirements for redundancy and, if needed, the system will be retained as part of the systems mix. Evaluating civil user requirements and determining a cost-effective mix of systems requires an open dialogue with civil users and international organizations, such as IMO and ICAO. It also requires a review of U.S. international commitments and resolution of any conflicts. DOD decides whether a given system is necessary to meet military requirements and if so, the system will be retained as part of the systems mix. An intensive effort is necessary and desirable to establish a stable framework for long-range planning by users and others affected by the transition to a new combination of systems. Consideration of operational, technical, economic, and institutional issues will dominate this selection process. However, the goal is to meet all military and civil requirements with the minimum number of common-use systems. Finally, a national policy will reflect: (1) national security requirements, (2) consultations with U.S. allies and civil users, and (3) DOD/DOT deliberations.

It must also be kept in mind that the provision of Government services for meeting user requirements is subject to the budgetary process, including authorizations and appropriations by Congress, and priorities for allocations among programs by agencies.

1.10.2 Operational Issues

Mobile users and operators want the safest, most direct, and most economical path to their destinations or, in some cases, the user wants to locate a fixed point or boundary. Users must be able to respond correctly and quickly to traffic control services. They must navigate with accuracy consistent with their environment, the capability of others sharing their space, the performance of their craft, and the rules, regulations, and procedures which govern operations. Areas of operation, mission, economics, personal preference, and Federal regulations largely determine the radionavigation aids chosen by operators. They choose different kinds of equipment to use the particular aid selected, and generally wish to limit or minimize the cost.

7.7 0.3 Special Military Considerations

A. Military Selection Factors

Operational need is the principal influence in the DOD selection process. Precise navigation is required for vehicles, anywhere on the surface of the Earth, under the sea, and in and above the atmosphere. Other factors that affect the selection process are:

- Flexibility to accommodate new weapon systems and technology.
- Immunity of systems to enemy interference or exploitation.
- Interoperability with the systems used by allies and the civil sector.
- Reliability and survivability in combat.
- Interruption, loss or degradation of system operation by enemy attack, political action, or natural causes.
- Development of alternate means of navigation.
- Geodetic accuracy relative to a common reference system, to support strategic and tactical operations.
- Worldwide mobility requirements.

B. Civil/Military Compatibility

DOD aircraft and ships operate in, and must be compatible with, civil environments. Thus, there are potential cost advantages in the development of common civil/military systems.

The activities experienced in activation of the maritime Ready Reserve Force during Desert Shield/Desert Storm have identified a potential need for improved navigation accuracy for ships involved in military sealift support. New GPS receiver concepts for systems with optional security modules are under consideration to be used when commercial ships are called into use in national emergencies.

C. Review and Validation

The DOD radionavigation system requirements review and validation process:

- Identifies the unique components of mission requirements.
- Identifies technological deficiencies.
- Determines, through interaction with DOT, the impact of new military requirements on the civil sector.

The requirements review and validation process will investigate system costs, user populations, and the relationship of candidate systems to other systems and functions.

1.10.4 Technical Considerations

In evaluating future radionavigation systems, there are a number of technical factors which must be considered:

- Received signal strength
- Multipath effects
- Signal accuracy
- Signal acquisition and tracking continuity
- Signal integrity
- Availability
- Vehicle dynamic effects
- Signal coverage
- Noise effects
- Propagation
- Interference effects (natural or man-made)
- Installation requirements
- Environmental effects
- Human factors engineering
- Reliability

1.10.5 Economic Considerations

The Government must continually review the costs and benefits of the navigation systems it provides. At the present time, there are several systems being operated by FAA, USCG, DOD and others. This continuing analysis can be used both for setting priorities for investment in new systems, and determining the appropriate mix of older systems to be retained. Only those systems that serve a significant number of users and provide the economic benefits in excess of costs should continue in operation. In some cases duplicate systems will have to be maintained for safety reasons and to allow adequate time for the transition to newer more accurate systems; however, older systems must be evaluated to determine whether or not their level of use is cost-effective.

The benefits from the Government operated navigation systems include improvements in economic productivity, operating efficiency, and accuracy in determining location. These factors allow planning for more fuel efficient routes and can prevent inadvertent diversions from the planned routes. Fuel savings can be in the billions of dollars. More precise location information can also be an important factor in preventing accidents. The efficiency benefits generally are the largest in dollar terms, but the safety benefits are very significant in justifying navigation systems.

The costs of navigation systems include capital investment, operating costs, and maintenance. These costs are borne by both the Government and the user. For new or replacement systems, the capital costs are significant. For existing systems, the operating and maintenance costs are the most important. Obtaining valid cost estimates is critical to analyzing the need for navigation systems.

Life cycle cost analysis is another important tool in decisions on navigation systems. When information is available on the actual operating and maintenance costs for a system, the life cycle cost analysis is very important in choosing between competing systems. Both DOD and DOT are increasingly aware of the need to minimize the life cycle costs in order to ensure the continued operation of navigation systems.

1.10.6 Institutional Considerations

The Department of Transportation Strategic Plan supports implementing GPS as the world's standard in the air, on land and over water. In order to accomplish this, there is a need to work with Congress, and all other interested parties, to develop a comprehensive, continuing and reliable funding program for the transportation navigation and positioning infrastructure.

A. Cost Recovery for Radionavigation Services

Use of present Federal radionavigation services cannot be easily measured; therefore, it would be difficult to assess direct user charges. Direct user charges normally involve a fee for each use of a specific system. Cost recovery for radionavigation services is either through general tax revenues or through transportation trust funds which are generally financed with indirect fees. These fees usually take the form of a fuel tax or value-added tax and can be used to pay all or part of an agency's costs.

It has been the general policy of the U.S. Government to recover the costs of Federally provided services that provide benefits to specific user groups. DOT plans to conduct a detailed analysis of costs and cost recovery mechanisms. Using existing user tax mechanisms, perhaps with some adjustments in rates to more equitably distribute the burden among different user groups, would be an efficient way of implementing a cost recovery policy.

At this point, the DOD-operated systems such as GPS are financed with general tax revenues. The USCG-operated systems are also operated with general tax revenues, although some amount of USCG outlays are offset by commercial vessel tonnage taxes. Aviation navigation systems are purchased with trust fund revenues and the systems are operated with a mix of general tax funds and trust funds. Introduction of GPS services will greatly increase the number of users to include automobiles, trains, transit, and land surveyors. The question is whether or not there is a better method for recovering the costs of GPS and other navigation systems that have widespread use. The Government will continue to study this issue.

B. Signal Availability in Times of National Emergency

The availability of accurate navigation signals at all times is essential for safe navigation. Conversely, guaranteed availability of optimum performance may diminish national security objectives, so that contingency planning is necessary. The U.S. national policy is that all radionavigation signals (Loran-C, Omega, VOR/DME, TACAN, GPS, augmented GPS, Transit, and radiobeacons) will be available at all times except during a dire national emergency as declared by the NCA, when only those radionavigation signals serving the national interest will be available.

C. International Acceptance of Navigational Systems

The goals of standardization and cost minimization of user equipment influence the search for an international consensus on a selection of radionavigation systems. For civil aviation, the ICAO establishes standards for internationally used radionavigation systems. For the international maritime community, a similar role is played by the IMO. Traditionally, IMO has been less stringent in establishing radionavigation requirements for the maritime community than ICAO has been for the aviation community. The IALA also develops international radionavigation guidelines. IMO is reviewing existing and proposed radionavigation systems to identify a system or systems that could meet the requirements of, and be acceptable to, members of the international maritime community.

In addition to technical and economic factors, national interests must also be considered in the determination of a system or systems to best meet the civil user's needs. Further international consultations will be required to resolve the issues.

D. Role of the Private Sector

Radionavigation services have historically been operated by the Government for reasons of safety and security, and to enhance commerce. These systems are used for air, land and marine applications, including navigation and positioning, and also for time and frequency dissemination.

For certain applications such as landing, positioning, and surveying, in areas where Federal systems are not justified, a number of privately operated systems are available to the user as an alternative or adjunct service. One application of privately provided DGPS supports Special Category I (SCAT-I) precision approaches. SCAT-I approaches are specially authorized by the FAA to Category I weather minima with DGPS used to provide navigation guidance. The FAA uses appropriate airworthiness and operational approval processes, based upon an aircraft operator's demonstrated capability and equipment, as well as the availability of approved ground equipment. Several commercial concerns are now also offering DGPS services for positioning and surveying applications. All operators using licensed U.S. communications links to transmit DGPS corrections are subject to constraints as directed by the NCA.

There is current interest in an increased private sector role in Federally provided radionavigation systems. Some of the factors to be considered in examining increased private sector involvement include:

- Impact of privately operated services on usage and demand for Federally operated services.
- Impact of permitting privately operated systems to provide basic safety of navigation services in conjunction with communications services.
- Need for a Federally provided safety of navigation service if commercial services are available.
- Liability considerations.
- Consideration of phase-over to private operation as a viable alternative to phase-out of a Federally operated radionavigation service.

1.10.7 *Criteria for Selection*

Criteria have been defined to compare alternative radionavigation system configurations. At the minimum, future systems should meet the following selection criteria:

A. Service: Necessary service should be provided to meet the needs of the military and civil communities.

- Military Operations: At a minimum, radionavigation services to support accomplishment of DOD tactical and strategic missions should be provided in an effective and efficient manner.
- Transportation Safety: At a minimum, radionavigation services sufficient to allow safe transportation should be provided.

- Economic Efficiency: To the extent possible and consistent with cost-effectiveness, radionavigation services which benefit the economy should be provided.

B. ***Viability: Radionavigation systems should be responsive and flexible to the changing operational and technological environments.***

- Evolving Technology: Research and introduction of new systems and concepts should be considered, particularly where unmet requirements or cost savings exist. Research, at the appropriate level, should continue for the life of the system.

- Orderly Transition: Modification and transition of systems should occur in an orderly manner to accommodate technical improvements.

- Flexibility: Radionavigation services should be provided to a variety of user classes with the minimum number of systems.

- Coverage: Radionavigation services should be provided in all relevant operating areas.

C. ***Standardization: A necessary degree of standardization and interoperability should be recognized and accommodated for both domestic and foreign operations.***

- International Acceptance: Navigation services and systems should be technically and politically acceptable to diverse groups, including NATO and other allies, ICAO, International Telecommunications Union, and IMO.

- Civil/Military Interoperability: The basic capabilities to permit common use and common operational procedures by civil and military users should be provided.

- Equipment Standardization and Compatibility: Civil and military navigation equipment should be compatible to the extent feasible. In addition, the number of transmission formats should be kept to a minimum in meeting diverse civil requirements.

D. ***Costs: The required level of service should be achieved in an economical manner.***

- Combined User/Government Costs: Life cycle costs of a mix of radionavigation systems for government and users should be consistent with adequate service and reasonable benefits.

- Transition Period Cost: Parallel (new and old) system operations should be carried out over a suitable transition period in consideration of user investment cost penalties and to permit equipment replacement to occur at reasonable intervals.

2

Radionavigation System User Requirements

The requirements of civil and military users for radionavigation services are based upon the technical and operational performance needed for military missions, transportation safety, and economic efficiency. For civil users, and for military users in missions similar to civil users (e.g., en route navigation), the requirements are defined in terms of discrete "phases of navigation." These phases are categorized primarily by the characteristics of the navigational problem as the mobile craft passes through different regions in its voyage. For example, the ship navigational problem becomes progressively more complex and risky as the large ship passes from the high seas, into the coastal area, and finally through the harbor approach and to its mooring. Thus, it is convenient to view each segment separately for purposes of analysis.

Unique military missions and national security needs impose a different set of requirements which cannot be viewed in the same light. Rather, the requirements for military users are more a function of the system's ability to provide services that equal or exceed tactical or strategic mission requirements at all times in relevant geographic areas, irrespective of hostile enemy action.

In the discussion that follows, both sets of requirements (civil and military) are presented in a common format of technical performance characteristics whenever possible. These same characteristics are used to define radionavigation system performance in Section 3.

2.1 Phases of Navigation

Each mode of transportation has various phases with different requirements to provide safe and cost-effective operation during each phase.

2.1.1 Air

The two basic phases of air navigation are en route/terminal and approach/landing.

A. En Route/Terminal

The en route/terminal phase includes all portions of flight except that within the approach/landing phase. It contains four subphases which are categorized by differing geographic areas and operating environments as follows:

1. Oceanic En Route: This subphase covers operations over ocean areas generally characterized by low traffic density and no independent surveillance coverage.
2. Domestic En Route (High Altitude and Low Altitude Routes): Operations in this subphase are typically characterized by moderate to high traffic densities. This necessitates narrower route widths than in the oceanic en route subphase. Independent surveillance is generally available to assist in ground monitoring of aircraft position.
3. Terminal Area: Operation in the terminal area is typically characterized by moderate to high traffic densities, converging routes, and transitions in flight altitudes. Narrow route widths are required. Independent surveillance is generally available to assist in ground monitoring of aircraft position.
4. Remote Areas: Remote areas are special geographic or environmental areas characterized by low traffic density and terrain where it has been difficult to cost-effectively implement comprehensive navigation coverage. Typical of remote areas are mountainous terrain, offshore areas, and large portions of the state of Alaska.

B. Approach/Landing

The approach/landing phase is that portion of flight conducted immediately prior to touchdown. It is generally conducted within 10 nautical miles (nm) of the runway. Two subphases may be classified as nonprecision approach and precision approach and landing.

2.1.2 Marine

Marine navigation in the U.S. consists of four major phases identified as inland waterway, harbor/harbor approach, coastal, and ocean navigation. Standards or requirements for safety of navigation and reasonable economic efficiency can be developed around these four phases. Specialized requirements, which may be generated by the specific activity of a ship, must be addressed separately.

A. Inland Waterway

Inland waterway navigation is conducted in restricted areas similar to those for harbor/harbor approach. However, in the inland waterway case, the focus is on nonseagoing ships and their requirements on long voyages in restricted waterways, typified by tows and barges in the U.S. Western Rivers System and the U.S. Intracoastal Waterway System.

In some areas, seagoing craft in the harbor phase of navigation and inland craft in the inland waterway phase share the use of the same restricted waterway. The distinction between the two phases depends primarily on the type of craft. It is made because seagoing ships and typical craft used in inland commerce have differences in physical characteristics, personnel, and equipment. These differences have a significant impact upon their requirements for aids to navigation. Recreational and other relatively small craft are found in large numbers in waters used by both seagoing and inland commercial traffic and generally have less rigid requirements in either case.

B. Harbor/Harbor Approach

Harbor/harbor approach navigation is conducted in waters inland from those of the coastal phase. For a ship entering from the sea or the open waters of the Great Lakes, the harbor approach phase begins generally with a transition zone between the relatively unrestricted waters where the navigational requirements of coastal navigation apply, and narrowly restricted waters near and/or within the entrance to a bay, river, or harbor, where the navigator enters the harbor phase of navigation. Usually, the harbor phase requires navigation of a well-defined channel which, at the seaward end, is typically from 180 to 600 meters in width if it is used by large ships, but may narrow to as little as 120 meters farther inland. Channels used by smaller craft may be as narrow as 30 meters.

From the viewpoint of establishing standards or requirements for safety of navigation and promotion of economic efficiency, there is some generic commonality between the harbor and harbor approach phases. In each case, the nature of the waterway, the physical characteristics of the vessel, the need for frequent maneuvering of the vessel to avoid collision, and the closer proximity to grounding danger impose more stringent requirements for accuracy and for real-time guidance information than for the coastal phase.

For analytical purposes, the phases of harbor approach and harbor navigation are built around the problems of precise navigation of large seagoing and Great Lakes ships in narrow channels between the transition zone and the intended mooring.

C. Coastal Navigation

Coastal navigation is that phase in which a ship is within 50 nm from shore or the limit of the continental shelf (200 meters in depth), whichever is greater, where a safe path of water at least one mile wide, if a one-way path, or two miles wide, if a two-way path, is available. In this phase, a ship is in waters contiguous to major land masses or island groups where transoceanic traffic patterns tend to converge in approaching destination areas; where interport traffic exists in patterns that are essentially parallel to coastlines; and within which ships of lesser range usually confine their operations. Traffic-routing systems and scientific or industrial activity on the continental shelf are encountered frequently in this phase of navigation. Ships on the open waters of the Great Lakes also are considered to be in the coastal phase of navigation.

The boundary between coastal and ocean navigation is defined by one of the following which is farthest from land:

- 50 nautical miles from land.
- The outer limit of offshore shoals, or other hazards on the continental shelf.
- Other waters where traffic separation schemes have been established, and where requirements for the accuracy of navigation are thereby made more rigid than the safety requirements for ocean navigation.

D. Ocean Navigation

Ocean navigation is that phase in which a ship is beyond the continental shelf (200 meters in depth), and more than 50 nm from land, in waters where position fixing by visual reference to land or to fixed or floating aids to navigation is not practical. Ocean navigation is sufficiently far from land masses so that the hazards of shallow water and of collision are comparatively small.

2.1.3 Land

In comparison with the air and marine communities, there are no well-defined phases of land navigation; however, there are different applications with unique accuracy requirements. The land navigation applications fall into four basic categories; highways, transit, rail, and non-transportation uses. Ongoing work on Intelligent Transportation Systems (ITS), which includes R&D and operational test programs using radionavigation that are wholly or partially funded by the Department of Transportation’s modal administrations (including FHWA, FTA, and NHTSA), will be used to clarify and validate user requirements.

A. Highways

Radionavigation techniques in highway applications are used individually or are integrated with vehicle-to-roadside communications and map-matching techniques to provide various user services. Some in-vehicle systems using radionavigation techniques are under development, some are being used in operational tests, and some are currently in use. Examples of systems in development include augmentation of GPS vehicle location data by providing DGPS correction values over wireless communications. Also under development is a system for vehicle location monitoring using GPS integrated with wireless packet data systems. Planned operational tests for ITS funded by FHWA include the use of radionavigation for automated vehicle location for mayday response, route guidance, mass transit scheduling, and mileage determination. Systems in use include radionavigation for dispatching roadside assistance vehicles and automated location tracking and scheduling of commercial vehicles. Radionavigation is used by various highway departments for asset management by using GPS coordinates to identify, for example, locations of bridges, highway signs, and overpasses. Table 2-l shows examples of ITS user services requiring the use of radionavigation. A full description of all of the ITS user services can be found in Appendix A.

B. Transit

Transit systems also benefit from the same radiolocation-based technologies used for highways. Automated vehicle location techniques assist in fleet management, scheduling, real-time customer information, and emergency assistance. Also, services such as automated transit stop annunciation are being investigated. There are several operational tests being funded by FTA to explore uses of radionavigation in transit systems for functions such as scheduling, automated dispatch, vehicle tracking, and traffic signal pre-emption.

C. Rail

The railroad industry may benefit from the use of radionavigation systems to aid in train location determination, monitoring, scheduling and management. These systems also have the potential for use in collision avoidance applications.

D. Non-Transportation Uses

Examples of non-transportation-based applications of radionavigation include meteorology; mapping, charting, geodesy, and surveying; precise timing; development of geographic information systems; and recreation uses. Surveying applications encompass densification control, corridor and project control, mapping control, structure control, cadastral surveys, and airborne GPS photogeometry control. The development of hand-held GPS receivers accompanied by declining prices is also opening markets for recreational uses such as hiking and backpacking.

Table 2-1. ITS User Services Requiring Use of Radionavigation

Travel and Traffic Management
Pre-Trip Travel Information
En Route Driver Information
Route Guidance
Incident Management
Travel Demand Management
Public Transportation Management
Public Transportation Management
Personalized Public Transportation
Commercial Vehicle Operations
Commercial Fleet Management
Emergency Management
Emergency Vehicle Management
Emergency Notification and Personal Security
Advanced Vehicle Safety Systems
Intersection Collision Avoidance

In general, geodesy and surveying have not been considered phases of navigation, but have provided the coordinate frames within which navigation is performed.

More recently, however, geodetic surveying methods have been used for position determination while in motion on land. As an example, one can profile an airport using kinematic DGPS on-the-fly methodology and obtain centimeter-accuracy profiles. This is an example of precise positioning while moving and not necessarily navigation in the full sense. Precision highway inventory management could be included as well.

Precise land navigation is in the development phase. A specific example of this might be agriculture. The exact trajectory of a tractor would be preprogrammed to plow, plant, fertilize, or harvest at the subdecimeter (or better) level. Certain pit-mining operations, heavy equipment operations such as excavating or bulldozing, and other possibilities such as highway equipment robotics fit this description.

The above examples are ones requiring centimeter accuracy navigation or positioning. There are many other land navigation activities which require decimeter to few-meter accuracy. The utility services might want to locate an underground main; a rancher may want to mark problem locations and return by way of waypoint navigation; a police investigator may want to mark and return to an accident site; and a search and rescue unit might want to drive by land vehicle or hike to a distress victim.

2.1.4 Space

For Earth-orbiting space activities, the mission phases can be generally categorized as the ground launch phase, the on-orbit phase, and the reentry and landing phase. In addition to the government sponsored space activities coordinated by NASA, there is a growing U.S. commercial space transportation industry seeking to launch both government and private payloads. There is also a growing private sector presence in space commerce that reflects sizable investments in such emerging uses as materials processing, land mobile services, radiodetermination, and remote sensing.

A. Ground Launch Phase

This phase is defined as that portion of the mission from the point at which a vehicle leaves the launch pad to the point wherein the vehicle inserts the payload into Earth orbit.

B. On-Orbit Phase

This is the phase wherein key operations or data gathering from an experiment to meet the primary mission objectives is performed. During this phase, the launch vehicle may deploy a satellite or perform positional maneuvers in support of onboard experiments. Vehicles capable of reentry may also retrieve a satellite for return to Earth. This phase essentially ends when the vehicle has completed its mission or initiates de-orbit maneuvers. In this phase, free-flying spacecraft perform their experiments and operations in their required orbits. In those cases where the spacecraft will not be returned to Earth, this operational phase continues until such time as the spacecraft is shut down or can no longer perform its functions. For those spacecraft to be returned to Earth, this phase essentially ends when the spacecraft is either retrieved by a reentry vehicle or returns to Earth on its own.

C. Reentry and Landing Phase

This phase begins when a reentry vehicle, possibly with onboard experiments or a retrieved spacecraft, initiates de-orbit maneuvers. The vehicle goes through atmospheric entry and makes an unpowered landing. This phase ends when the vehicle comes to a full stop.

2.2 Civil Radionavigation System Requirements

The radionavigation requirements of civil users are determined by a DOT process which begins with acknowledgment of a need for service in an area or for a class of users. This need is normally identified in public safety and cost/benefit need analysis generated internally, from other Federal agencies, from the user public, or as required by Congress. User conferences have highlighted land user needs not previously defined.

Radionavigation services provide civil users with the following:

- Service adequate for safety.
- Economic performance/benefit enhancement.
- Support of an unlimited number of users.
- Continuous availability for fix information.

Radionavigation system replacement candidates must be subjected to a total system analysis in terms of safety and economic performance. This involves the evaluation of a number of complex factors. Replacement decisions will not be made on the basis of a simple comparison of one performance characteristic such as system accuracy.

It must also be kept in mind that the provision of Government services for meeting user requirements is subject to the budgetary process, including authorizations and appropriations by Congress, and priorities for allocations among programs by agencies.

2.2.7 Process

The requirements for an area or class of users are not absolutes. The process to determine requirements involves:

- Evaluation of the acceptable level of safety risks to the Government, user, and general public as a function of the service provided.
- Evaluation of the economic needs in terms of service needed to provide cost-effective benefits to commerce and the public at large. This involves a detailed study of the service desired measured against the benefits obtained.
- Evaluation of the total cost impact of any government decision on radionavigation system users.

This process leads to government selection of a system. The decision is driven primarily by considerations of safety and economic benefit.

2.2.2 User Facfors

User factors requiring consideration are:

- Vehicle size and maneuverability.
- Regulated and unregulated traffic flow.
- User skill and workload.
- Processing and display requirements for navigation and positioning information.
- Environmental constraints; e.g., weather, terrain, or man-made obstructions.
- Operational constraints inherent to the system.
- Safety constraints.
- Economic benefits.

For most users, cost is generally the driving consideration. The price users are willing to pay for equipment is influenced by:

- Activity of the user; e.g., recreational boaters, air taxi, general aviation, mineral exploration, helicopters, commercial shipping, and positioning, surveying, and timing.
- Vehicle performance variables such as fuel consumption, operating costs, and cargo value.
- Cost/performance trade-offs of radionavigation equipment.

Thus, in the civil sector, evaluation of a navigation system against requirements involves more than a simple comparison of accuracy and equipment performance characteristics. These evaluations must involve the operational, technical, and cost elements discussed above. Performance requirements are defined within this framework.

2.3 Civil Air Radionavigation Requirements

Aircraft navigation is the process of piloting aircraft from one place to another and includes position determination, establishment of course and distance to the desired destination, and determination of deviation from the desired track. Requirements for navigational performance are dictated by the phase of flight and their relationship to terrain, to other aircraft, and to the air traffic control process. Aircraft navigation may be achieved through the use of visual procedures during Visual Flight Rules

(VFR) operations but requires navigation avionics when operating under Instrument Flight Rules (IFR) or above Flight Level (FL) 180 (18,000 ft).

Aircraft separation criteria, established by the FAA, take into account limitations of the navigational service available and, in some airspace, the Air Traffic Control (ATC) surveillance service. Aircraft separation criteria are influenced by the quality of navigational service, but are strongly affected by other factors as well. The criteria relative to separation require a high degree of confidence that an aircraft will remain within its assigned volume of airspace. The dimensions of the volume are determined, in part, by a stipulated probability that performance of the navigation system will not exceed a specified error.

Since navigation is but one function performed by the pilot, the workload for navigation in conjunction with communications, flight control, and engine monitoring must be small enough so that the pilot has time to adequately see and avoid other aircraft when operating using see-and-avoid rules.

The following are basic requirements for the aviation navigation systems. "Navigation system" means all of the elements necessary to provide navigation services to each phase of flight. While navigation systems are expected to be able to meet these requirements, implementation of specific capabilities is to be determined by the users and, where appropriate, regulatory authorities.

No single set of navigational and operational requirements, even though they meet the basic requirement for safety, can adequately address the many different combinations of operating conditions encountered in various parts of the world. Requirements applicable to the most exacting region may be considered extravagant when applied to others. In general,

a. The navigation system must be suitable for use in all aircraft types which may require the service without unduly limiting the performance characteristics or utility of those aircraft types; e.g., maneuverability and fuel economy.

b. The navigation system must be safe, reliable, and available; and appropriate elements must be capable of providing service over all the used airspace of the world, regardless of time, weather, terrain, and propagation anomalies.

c. The integrity of the navigation system, including the presentation of information in the cockpit, shall be near 100 percent and, to the extent feasible, should provide timely alarms in the event of failure, malfunction, or interruption.

d. The navigation system must recover from a temporary loss of signal without the need for complete resetting.

e. The navigation system must provide in itself maximum practicable protection against the possibility of input blunder, incorrect setting, or misinterpretation of output data.

f. The navigation system must provide adequate means for the pilot to check the accuracy of airborne equipment.

g. The navigation information provided by the systems must be free from unresolved ambiguities of operational significance.

h. Any source-referenced element of the total navigation systems shall be capable of providing operationally acceptable navigational information simultaneously and instantaneously to all aircraft which require it within the area of coverage.

i. In conjunction with other flight instruments, the navigation system must in all circumstances provide information to the pilot and aircraft systems for performance of the following functions:

- Continuous track deviation guidance.
- Continuous determination of distance along track.
- Continuous determination of position of aircraft.
- Position reporting.
- Manual or automatic flight.

j. The navigation system must be capable of being integrated into the overall ATC system.

k. The navigation system should be capable of integration with all phases of flight, including the precision approach and landing system. It should provide for transition from long-range (overwater) flight to short-range (domestic) flight with minimum impact on cockpit procedure/displays and workload.

l. The navigation system must permit the pilot to determine the position of the aircraft with an accuracy and frequency that will (a) ensure that the separation minima can be maintained at all times, (b) execute properly the required holding and approach patterns, and (c) maintain the aircraft within the area allotted to the procedures.

m. The navigation system must permit the establishment and the servicing of any practical defined system of routes for the appropriate phases of flight.

n. The system must have sufficient flexibility to permit changes to be made to the system of routes and siting of holding patterns without imposing unreasonable inconvenience or cost to the providers and the users of the system.

o. The navigation system must be capable of providing the information necessary to permit maximum utilization of airports and airspace.

p. The navigation system must be cost-effective to both the Government and the users.

q. The navigation system must employ equipment to minimize susceptibility to interference from adjacent radio-electronic equipment and shall not cause objectionable interference to any associated or adjacent radio-electronic equipment installation in aircraft or on the ground.

r. The navigation system must be free from signal fades or other propagation anomalies within the operating area.

s. The navigation system must be capable of furnishing reduced service to aircraft with limited or partially inoperative equipment.

t. The navigation system must be capable of being coupled with the aircraft flight control system to provide automatic tracking.

2.3.1 Navigafion Signal Error Characferisfics

The unique signal characteristics of a navigation system have a direct effect on determining minimum route widths. The distribution and rate of change, as well as magnitude of the errors, must be considered. Error distributions may contain both bias and random components. The bias component is generally easily compensated for when its characteristics are constant and known. For example, VOR radials can be flight-checked and the bias error reduced or eliminated through correction of the radial used on aeronautical charts.

The Loran-C and Omega seasonal and diurnal variations can also be compensated for by implementing correction algorithms in aircraft equipment logic and by publishing corrections periodically for use in air equipment.

The distribution of the random or unpredictable varying error component becomes the critical element to be considered in the design of navigation systems. The rate of change of the error within the distribution is also an important factor, especially when the system is used for approach and landing.

Errors varying at a very high frequency can be readily integrated or filtered out in the aircraft equipment. Errors occurring at a slower rate can be troublesome and result in disconcerting indications to the pilot. An example of one of these would be a “scalloped” VOR signal that causes the Course Deviation Indicator (CDI) to vary. If the pilot attempts to follow the CDI closely, the plane will start to “S” turn frequently. The maneuvering will cause unnecessary pilot workload and degrade pilot confidence in the navigation system. This indication can be further aggravated if navigation systems exhibit different error characteristics during different phases of flight or when the aircraft is maneuvering. The method of determining the total system error is affected by the navigation signal error characteristics. In most current systems the error components are ground system errors, airborne receiver errors, and flight technical errors. These errors are combined using the Root-Sum-Square (RSS) method. In analyzing new systems, it may be necessary to utilize alternative methods of combining errors, but each element must be properly considered.

In summary, the magnitude, nature, and distribution of errors as a function of time, terrain, aircraft type, aircraft maneuvers, and other factors must be considered. The evaluation of errors is a complex process, and the comparison of systems based upon a single error number will be misleading.

2.3.2 Current Aviafion Navigafion Requiremenfs

The current aviation navigation requirements for all phases of flight are listed in Table 2-2.

En Route/Terminal Phase: The en route/terminal phase of air navigation (as defined in Section 2.1.1 .A) includes the following subphases:

- Oceanic En Route
- Domestic En Route
- Terminal Area
- Remote Area

The general requirements in Section 2.3 are applicable to the en route/terminal phase of flight. In addition, to facilitate aircraft navigation in this phase, the system must be capable of being operationally integrated with the system used for approach and landing.

Federal Aviation Regulations (FAR) paragraphs 9 1.119 and 9 1.121 specify the vertical separation required below and above FL 290. The current separation requirement is 1,000 feet below FL 290, and 2,000 feet at and above FL 290. In order to justify the 1 ,OOO-foot vertical separation below FL 290, the RSS altitude keeping requirement is ±350 feet (3 sigma). This error is comprised of ±250 feet (3 sigma) aircraft altimetry system error, of which the altimeter error is limited to ±125 feet by Technical Standard Order (TSO) C-1OB below FL 290.

The minimum performance criteria currently established to meet requirements for the en route/terminal phase of flight are presented in the following sections.

A. Oceanic En Route

The system must provide navigational capability commensurate with the need in specific areas in order to permit safe navigation and the application of lateral separation criteria. An organized track system has been implemented in the North Atlantic to gain the benefit of optimum meteorological conditions. Since an independent surveillance system such as radar is not available, separation is maintained by procedural means (e.g., position reports and timing).

Table 2-2. Controlled Airspace Navigation Accuracy Requirements

PHASE	SUB-PHASE		ALTITUDE FUFT	TRAFFIC DENSITY	ROUTE WIDTH (nm)	SOURCE ACCURACY CROSS -TRACK (95%, nm)	SYSTEM USE ACCURACY CROSS -TRACK (95%, nm)
EN ROUTE/ TERMINAL	Oceanic		FL 275 to 400	Normal	60*	12.4”	12.6*
	Domestic		FL 180 TO 600	Low	16	2.8	3.0
				Normal	8	2.8	3.0
			500 FT to FL 180	High	8	2.8	3.0
	Terminal		500 FT to FL 180	High	4	1.7	2.0
APPROACH AND LANDING	Nonprecision		250 to 3,000 FT	Normal	N/A	0.3	0.6
	Precision	CAT I	N/A	Normal	N/A	+/-17-l ** ¦ +/-4.1 *** CAT I Decision Height Point ****	N/A
		CAT II	N/A	Normal	N/A	+/-5.2 ** ¦ d-1.7 *** CAT II Decision Height Point ****	N/A
		CAT III	N/A	Normal	N/A	+/-4.1 ** ¦ +/- 0.6 *** At Runway Threshold ****	N/A

* *North Atlantic Track System requirements.*
** *Lateral position accuracy in meters.*
*** *Vertical position accuracy in meters.*
**** *Assumes a 3° glideslope and 8,000 ft. distance between runway threshold and localizer antenna.*

The lateral separation standard on the North Atlantic organized track system is 60 nm. The following system performance is required to achieve this separation:

1. The standard deviation of the lateral track errors shall be less than 6.3 nm, 1 sigma (12.6 nm, 2 sigma).

2. The proportion of the total flight time spent by aircraft 30 nm or more off track shall be less than 5.3 x 10^{-4}; i.e., less than 1 hour in 2,000 flight hours.

3. The proportion of the total flight time spent by aircraft between 50 and 70 nm off track shall be less than 1.3 x 10^{-4}; i.e., approximately 1 hour in 8,000 flight hours.

B. Domestic En Route

Domestic air routes are designed to provide airways that are as direct as practical between city pairs having significant air traffic. For VOR-defined routes, via navaids or radials, the protected airspace at FL 600 and below is 4 nm on each side of the route to a point 5 1 nm from the navaid, then increases in width on either side of the centerline at a 4.5 degree angle to a width of 10 nm on each side of the route at a distance of 130 nm from the navaid.

Current accuracy requirements for domestic en route navigation are based on the characteristics of the VOR/DME/VORTAC system and therefore relate to the angular characteristics of the VOR and TACAN azimuth systems and range characteristics of the distance measuring equipment (DME)/TACAN range systems. “System Use Accuracy,” as defined by ICAO, is the RSS of the ground station error contribution, the airborne receiver error, the display system contribution, and the Flight Technical Error (FTE). FTE is the contribution of the pilot (or autopilot) in using the presented information to control aircraft position. Error values on which the current system is based are as follows:

1. Azimuth Accuracy in Degrees:

Error Component	2 Sigma Deviation Values	Source
VOR Ground	+1.4°	Semi-Automatic Flight Inspection (SAFI) System
VOR Air	+3.0°	Equipment Manufacturer
Course Selection (CSE)	+2.0°	FAA Tests
Flight Technical (FTE)	+2.3°	FAA Tests
System Use Accuracy (95 % Confidence)	+4.5°	(RSS derived)

2. Range Accuracy

Where DME service is used, the system use accuracy is defined as ±O.5 nm or 3 percent of distance (2 sigma), whichever is greater. This value covers all existing DME avionics. When DME is used with an RNAV system, the range accuracy must be at least ±O.2 nm plus 1 percent of the distance (2 sigma).

3. Area Navigation (RNAV)

RNAV computation equipment provides latitude and longitude coordinate navigation capability. When RNAV equipment is used, an additional error contribution is specified and combined in RSS fashion with the basic VOR/DME system error. The additional maximum RNAV equipment error allowed, per FAA Advisory Circular AC 90-45A, is ±0.5 nm. RNAV system performance and route design is based on the following error budget:

Error Component	2 Sigma Deviation Values	Source
VOR Ground	+1.4º	SAFI
VOR Air	+3.0°	Equipment Manufacturer and FAA Tests
DME Ground	+0.1 nm	SAFI

The VOR/DME and RNAV error values identified below result in 95 percent of the aircraft remaining within ±4 nm of the airway centerline out to 51 nm from a VOR facility and within ±4.5 degrees (originating at the VOR facility) of the airway centerline when beyond 51 nm from a VOR facility.

Error Component	2 Sigma Deviation Values	Source
DME Air	+0.2 nm + 1% of Range	Equipment Manufacturer*
FTE	+l .O nm	FAA Tests**
CSE	+2.0°	FAA Tests
RNAV System	+0.5 nm	Equipment Manufacturer and FAA Tests

*Only DME aircraft equipment with this accuracy or better is used.
**FTE - 0.5 nm in the approach phase.

C. Terminal Area

Terminal routes provide transitions from the en route phase to the approach phase of flight. The accuracy capability of navigation systems using VOR/DME in terms of bearing and distance to the facility is defined in the same manner as described for en route navigation. However, the usually closer proximity to facilities provides greater effective system use accuracy since both VOR and FTE are angular in nature and are related to the distance to the facility. The DME distance error is also reduced, since it is proportional to distance from the facility, down to the minimum error capability. Thus the system use accuracy requirement is +2 nm (95 percent) within 25 nm of the facility, based on the RSS the combination of error elements.

D. Remote Areas

Remote areas are defined as regions which do not meet the requirements for installation of VOR/DME service or where it is impractical to install this system. These include offshore areas, mountainous areas, and a large portion of the state of Alaska. Thus the minimum route width varies and can be greater than ±lO nm.

E. Operations Between Ground Level and 5,000 Feet Above Ground Level (AGL)

Operations between ground level and 5,000 feet AGL occur in offshore, mountainous, and high-density metropolitan areas as well as on domestic routes. For operations from U.S. coastline to offshore points, the following requirements must be met:

- Range from shore to 300 nm.
- Minimum en route altitude of 500 feet above sea level or above obstructions.
- Accuracy adequate to support routes ±4 nm wide or narrower with 95 percent confidence.
- Minimum descent altitude to 100 feet in designated areas.

For helicopter operations over land, the following requirements must be met:

- Accuracy adequate to support ±2 nm route widths in both en route and terminal areas with 95 percent confidence.
- Minimum en route altitudes of 1,200 feet AGL.
- Navigation signal coverage adequate to support approach procedures to minimums of 250 feet above obstruction altitudes at heliports and airports.

Approach/Landing Phase: This phase of flight is one of two types: (1) nonprecision approach, or (2) precision approach and landing.

The general requirements of Section 2.3 apply to the approach/landing phase. In addition, specific procedures and clearance zone requirements are specified in TERPS (United States Standard for Terminal Instrument Procedures, FAA Handbook 8260.3B).

Altimetry accuracy requirements are established in accordance with FAR 91.411 and are the same as those for the en route/terminal phase.

The minimum performance criteria currently established to meet requirements for the approach/landing phase of navigation vary between precision and nonprecision approaches.

A. Nonprecision Approach

Nonprecision approaches are based on any navigational system that meets the criteria established in TERPS. Minimum safe altitude, obstacle clearance area, visibility minimum, final approach segment area, etc., are all functions of the navigational accuracy available and other factors. The unique features of RNAV for nonprecision approaches are specified in FAA Advisory Circulars No. 90-45A, "Approval of Area Navigation Systems for Use in the U.S. National Airspace System;" No. 20-130, "Airworthiness Approval of Multi-Sensor Navigation Systems in U.S. National Airspace System (NAS) and Alaska;" 20- 12 1 A, "Airworthiness Approval of the Loran-C Navigation System for Use in U.S. National Airspace (NAS) and Alaska;" and TSO C 129, "Airborne Supplemental Navigation Equipment Using the Global Positioning System."

The achieved capability for nonprecision approaches varies significantly, depending on the location of the navigational facility in relation to the fix location and type of navigational system used. Approximately 30 percent of the nonprecision approach fixes based on VOR in the U.S. achieve a cross track navigational accuracy of ±lOO meters (2 sigma) at the missed approach point (MAP). This accuracy is based upon the ±4.5 degrees VOR system use accuracy and the MAP being less than 0.7 nm from the VOR facility.

Nonprecision RNAV approaches must satisfy their own criteria and are based on the obstacle clearance areas shown in Figure 2-1. The width of the intermediate approach trapezoid primary areas decreases from 4 nm (2 nm each side of the route centerline) at the end of the intermediate fix or waypoint displacement area to 2 nm (1 nm each side of the route centerline) at the final approach fix or waypoint. Primary obstacle clearance areas further narrow to the width of the runway waypoint fix displacement area at its furthest point. Secondary areas (not depicted) also extend upward and outward from the sides of the primary area.

The integrity time-to-alarm requirement for nonprecision approaches provides the pilot with either a warning or a removal of signal within 10 seconds of the occurrence of an out-of-tolerance condition.

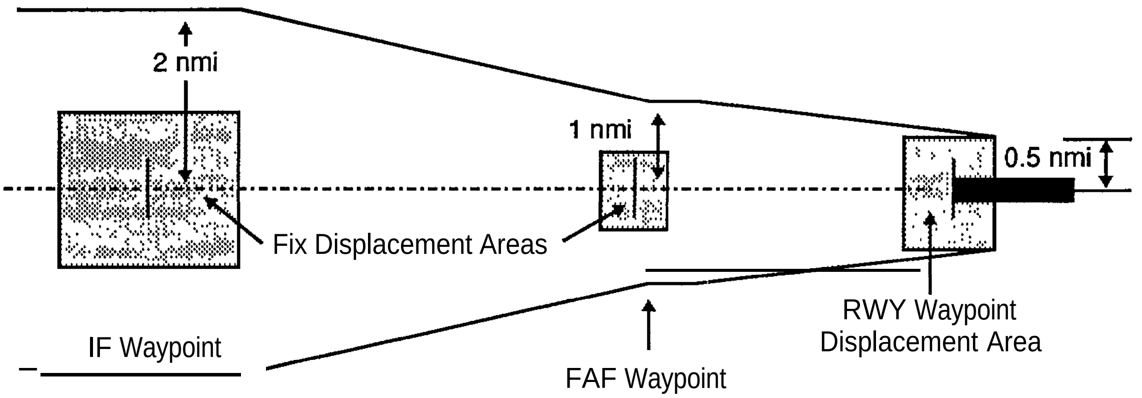


Figure 2- 1. RNAV Nonprecision Approach Protected Areas

B. Precision Approach and Landing

Precision approach and landing radio aids provide vertical and horizontal guidance and position information. ILS and MLS are of this type. International agreements have been made to achieve an all-weather landing capability through an evolutionary process, reducing landing weather minima on a step-by-step basis as technical capabilities and operational knowledge permit. The performance objectives for the various landing categories are shown in Table 2-2.

The MLS and ILS system integrities, during precision approaches, warn the pilot of an out-of-tolerance condition by removing these signals from service. The response time for providing these warnings varies from six seconds for Category I to two seconds for Category II/III.

C. Current System Requirements Summary

The system use accuracy criteria to meet the current route requirements are summarized in Table 2-2. These route widths are based upon present capacities, separation requirements, and obstruction clearance requirements. Availability requirements are being developed.

23.3 Future Aviation Radionavigation Requirements

Future aviation navigation requirements will be based on new criteria using the concept of required navigation performance (RNP). This concept will be developed such that unified criteria will be established for airworthiness approval, ground equipment approval (if required), operating approval, establishment of operating minima and obstacle clearance assessment. Aviation requirements in the next edition of the FRP are expected to be expressed using this method.

Altimetry requirements for vertical separation of 1,000 feet, below FL 290, are not expected to change. Increased altimetry accuracy is needed at and above FL 290 to permit separation less than the current standard of 2,000 feet. The required future 3 sigma value of the aircraft altimetry system error has not been specified, but it must be accurate enough to support the introduction of 1,OOO-foot vertical separation at all flight levels.

En Route/Terminal Phase

A. Oceanic En Route

Separation specifications have been designed to allow a lateral separation of 60 nm. This was put into effect for certain areas of the North Atlantic in early 1981 and requires a lateral track error less than 12.6 nm (95 percent). More accurate and reliable aircraft position data will greatly contribute to reductions in lateral separation, resulting in greater flexibility and the ability to fly user-preferred routes.

B. Domestic En Route

At the present time, the number of VOR/DMEs is sufficient to allow most routes to have widths of ±4 nm. This is possible as most VOR facilities are spaced less than 100 nm apart on the route. However, greater spacings are used in low traffic density areas, remote areas, and on most of the high-altitude route structure. Parts of the high-altitude route structure have a distance between VOR facilities resulting in route widths up to 20 nm.

Traffic increases are causing route capacity problems. More use of RNAV equipment will allow the implementation of random and parallel routes not possible with the use of current VOR/DME facilities. No increase in VOR/DME ground accuracy is required to meet the navigational requirements imposed by the air traffic levels estimated for the year 2000.

C. Terminal Area

The major change forecasted for the terminal area is the increased use of RNAV and time control to achieve optimum runway utilization and noise abatement procedures. Some current multi-DME RNAV avionics can provide cross track navigational accuracies better than ±500 meters (2 sigma) in terminal areas using the current VOR/DME facilities. Similarly, GPS-based avionics deliver better accuracies and performance than VOR/DME in the terminal area.

D. Remote Areas

Many areas, such as Alaska, the Rocky Mountains and other mountainous areas, and some offshore locations, cannot be served easily or at all by VORDME. Presently, nondirectional beacons (NDB), Omega, and privately owned facilities such as

TACAN are being used in combination to meet the user navigational needs in these areas. GPS, Omega and Loran-C are being used as supplements to VOR/DME to meet these needs. The accuracy and coverage of these systems seem adequate to handle the traffic densities projected for the different areas.

Approach/landing Phase

A. Nonprecision Approach

No changes are envisioned at this time to the nonprecision approach obstacle clearance areas.

B. Precision Approach and Landing

Future requirements for precision approaches are expected to be based on required navigation performance and the developing "tunnel concept." These requirements will describe a 95 percent containment accuracy surface and a 10^{-7} outer containment surface. The associated accuracy requirements are depicted in Figure 2-2.

2.4 Civil Marine Radionavigation Requirements

The navigational requirements of a vessel depend upon its general type and size, the activity in which the ship is engaged (e.g., point-to-point transit, fishing) and the geographic region in which it operates (e.g., ocean, coastal), as well as other factors. Safety requirements for navigation performance are dictated by the physical constraints imposed by the environment and the vessel, and the need to avoid the hazards of collision, ramming, and grounding.

The above discussion of phases of marine navigation (Section 2.1.2) sets the framework for defining safety of navigation requirements. However, the economic and operational dimensions also need to be considered for the wide diversity of vessels that traverse the oceans and U.S. waters. For example, navigation accuracy (beyond that needed for safety) is particularly important to the economy of large seagoing ships having high hourly operating costs. For fishing and oil exploration vessels, the ability to locate precisely and return to productive or promising areas and at the same time avoid underwater obstructions or restricted areas provides important economic benefits. Search and Rescue (SAR) effectiveness is similarly dependent on accurate navigation in the vicinity of a maritime distress incident.

For system planning, the Government seeks to satisfy minimum safety requirements for each phase of navigation and to maximize the economic utility of the service for users. Since the vast majority of marine users are required to carry only minimal navigational equipment, and even then do so only if persuaded by individual cost/benefit analysis, this governmental policy helps to promote maritime safety through a simultaneous economic incentive.

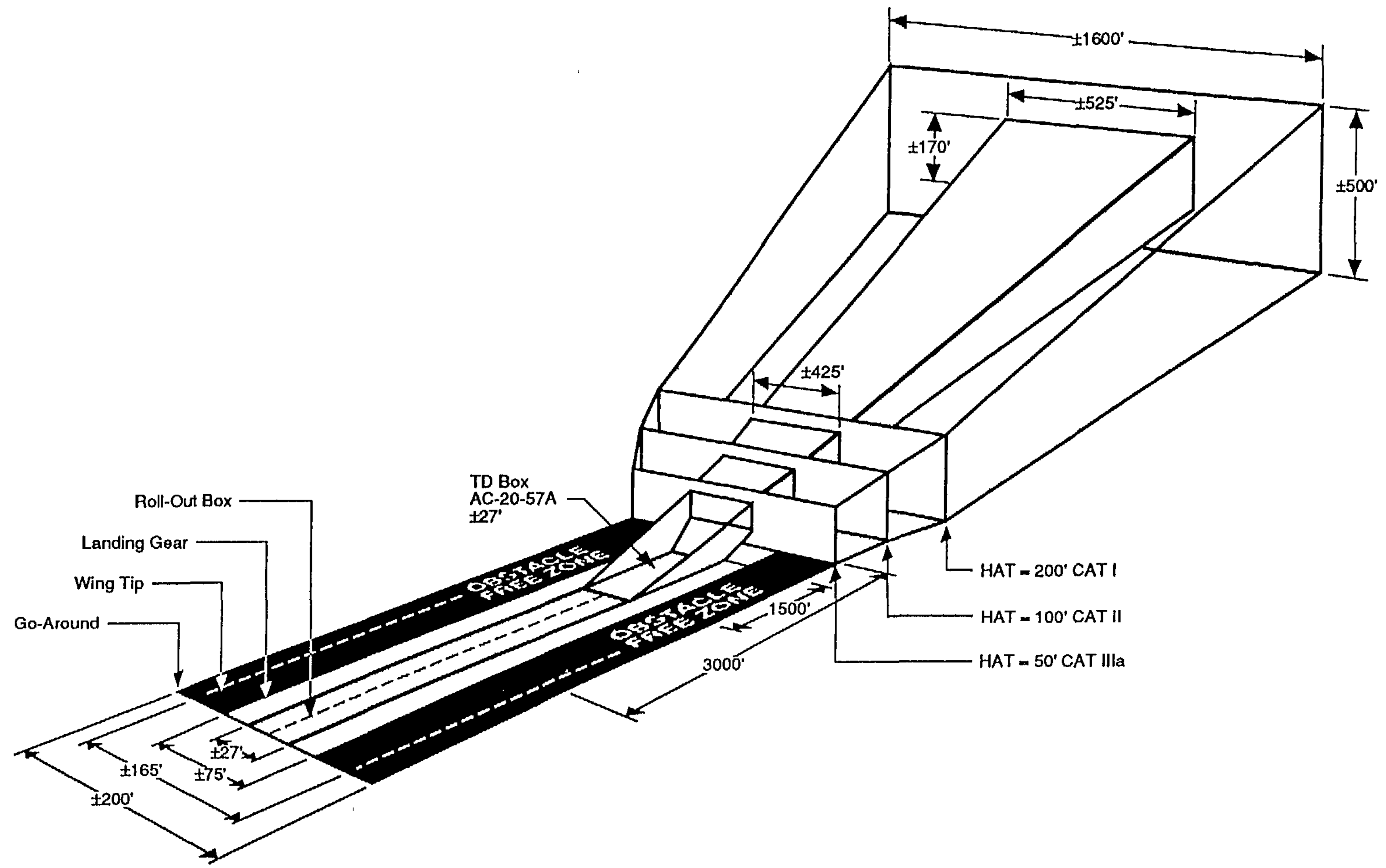


Figure 2-2. RNP for Precision Approach and Landing Tunnel

Tables 2-3,2-4, and 2-5 identify system performance needed to satisfy maritime user requirements or to achieve special benefits in three of the four phases of marine navigation. The tables are divided into two categories. The upper half are those related to safety of navigation. The Government recognizes an obligation to satisfy these requirements for the overall national interest. The lower half are specialized requirements or characteristics needed to provide special benefits to discrete classes of maritime users (and additional public benefits which may accrue from services provided by users). The Government does not recognize an absolute commitment to satisfy these requirements, but does endeavor to meet them if their cost can be justified by benefits which are in the national interest. For the purpose of comparing the performance of systems, the requirements are categorized in terms of system performance characteristics representing the minimum performance considered necessary to satisfy the requirements or achieve special benefits.

2.4.1 Inland Waterway Phase

Very large amounts of commerce move *on* the U.S. inland waterway system, much of it in slow-moving, comparatively low-powered tug and barge combinations. Tows on the inland waterways, although comparatively shallow in draft, may be longer and wider than large seagoing ships which call at U.S. ports. Navigable channels used by this inland traffic are often narrower than the harbor access channels used by large ships. Restricted visibility and ice cover present problems in inland waterway navigation, as they do in harbor/harbor approach navigation. The long, ribbon-like nature of the typical inland waterway presents special problems to the prospective user of precise, land-based area navigation systems. Continual shifting of navigable channels in some unstable waters creates additional problems to the prospective user of any radionavigation system which provides position measurements in a fixed coordinate system.

Special waterways, such as the Saint Lawrence River and some Great Lakes passages, are well defined, but subject to frequent fog cover which requires ships to anchor. This imposes a severe economic penalty in addition to the safety issues. If a fog rolls in unexpectedly, a ship may need to proceed under hazardous conditions to an anchorage clear of the channel or risk stopping in a channel.

Requirements: Requirements based on the consideration of practically achievable performance and expected benefits have not been defined. However, Research, Engineering and Development (R,E&D) in harbor/harbor approach navigation is expected to produce results which will have some application to inland waterway navigation.

Minimum Performance Criteria: These criteria have not been determined. The R,E&D plans in Section 4 discuss the current and future efforts in the area of inland waterway navigation.

Table 2-3. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Harbor/Harbor Approach Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (meters, 2dmms)		COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEMS CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
SAFETY OF NAVIGATION - LARGE SHIPS & TOWS	8-20***	-	US harbor & harbor approach	99.7%	**	6-1 0 seconds	Two	Unlimited	Resolvable with 99.9% confidence
SAFETY OF NAVIGATION - SMALLER SHIPS	8-20	8-20	US harbor & harbor approach	99.9%	**	***	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE EXPLORATION	1-5*	1-5m*	US harbor & harbor approach	99%	**	1 second	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
FISHING, RECREATIONAL & OTHER SMALL VESSELS	8-20	4-10	US harbor &harbor approach	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% confidence

* Based on stated user need.
** Dependent upon mission time.
*** Varies from one harbor to another. Specific requirements are being reviewed by the Coast Guard.

Table 2-4. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Coastal Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
	ACCURACY (meters, 2drms)		COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE							
SAFETY OF NAVIGATION ALL SHIPS	0.25nm (460m)	-	us coastal waters	99.7%	**	2 minutes	Two	Unlimited	Resolvable with 99.9% confidence
SAFETY OF NAVIGATION RECREATION BOATS&OTHER SMALLER VESSELS	0.25nm-2nm (469-3,7OOm)	-	us coastal waters	99.	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS								
COMMERCIAL FISHING (INCLUDING COMMERCIAL SPORT FISHING)	0.25nm (460m)	(15-180m)	us coastal/ fisheries areas	99%	**	1minute	Two	Unlimited	
RESOURCE EXPLORATION	1.0-100m*	1.0-100m*	US coastal areas	99%	**	1 second	Two	Unlimited	
SEARCH OPERATIONS, LAW ENFORCEMENT	0.25nm (460m)	300-600ft (90-180m)	US coastal/ fisheries areas	99.7%	**	1 minute	Two	Unlimited	
RECREATIONAL SPORTS FISHING	0.25nm (460m)	100-600 ft (30-180m)	US coastal areas	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence

* Based on stated user need.
** Dependent upon mission time.

Table 2-5. Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Ocean Phase

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS									
	ACCURACY (2 drms)			COVERAGE	AVAILABILITY	RELIABILITY	FIX INTERVAL	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY
	PREDICTABLE	REPEATABLE	RELATIVE							
SAFETY OF NAVIGATION ALL CRAFT	24nm (3.7-7.4km) minimum 1-2nm (1.8-3.7km) desirable	-		Worldwide	99% fix at least every 12 hours	**	15 minutes or less desired; 2 hours maximum	Two	Unlimited	Resolvable with 99.9% confidence

BENEFITS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS									
LARGE SHIPS MAXIMUM EFFICIENCY	0.1-0.25nm* (185-460m)	-		Worldwide, except polar regions	99%	**	5 minutes	Two	Unlimited	Resolvable with 99.9% confidence
RESOURCE EXPLORATION	10-100m*	10-100m*	-	Worldwide	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence
SEARCH OPERATIONS	0.1-0.25nm (460m)	0.25nm	185m	National maritime SAR regions	99%	**	1 minute	Two	Unlimited	Resolvable with 99.9% confidence

* Based on stated user need.
** Dependent upon mission time.

2.4.2 Harbor/Harbor Approach Phase (HHA)

The pilot of a vessel in restricted waters must direct its movement with great accuracy and precision to avoid grounding in shallow water, hitting submerged/partially submerged rocks, and colliding with other craft in congested waterways. Unable to turn around, and severely limited in the ability to stop to resolve a navigational problem, the pilot of a large vessel (or a tow boat and barge combination) may find it necessary to hold the total error in navigation within limits measured in a few feet while navigating in this environment. It would appear that a major step in maximizing the effectiveness of radionavigation systems in the harbor/harbor approach environment is to present the position information on some form of electronic display. This would provide a ship's captain, pilot, or navigator a continual reference, as opposed to plotting "outdated" fixes on a chart to show the recent past. It is also recognized that the role of the existing radionavigation system decreases in this harbor/harbor approach environment, while the role of visual aids and radar escalates.

Requirements: To navigate safely, the pilot needs highly accurate verification of position almost continuously, together with information depicting any tendency for the vessel to deviate from its intended track and a nearly continuous and instantaneous indication of the direction in which the pilot should steer. Table 2-3 was developed to present estimates of these requirements. To effectively utilize the requirements stated in the table, however, a user must be able to relate the data to immediate positioning needs. This is not practical if one attempts to plot fixes on a chart in the traditional way. To utilize radionavigation information that is presented at less than lo-second intervals on a moving vessel, some form of an automatic display is required. Technology is available which presents radionavigation information along with other data.

Minimum Performance Criteria: The radionavigation system accuracy required to provide useful information in the harbor/harbor approach phase of marine navigation varies from harbor to harbor, as well as with the size of the vessel. In the more restricted channels, accuracy in the range of 8 to 20 meters (2 drms) relative to the channel centerline may be required for the largest vessels. A need exists to more accurately determine these radionavigation requirements for various-sized vessels while operating in such restricted confines. Radionavigation user conferences have indicated that for many mariners, the radionavigation system becomes a secondary tool when entering the harbor/harbor approach environment.

Continuing efforts are being directed toward verifying user requirements and desires for radionavigation systems in the harbor/harbor approach environment.

2.4.3 Coastal Phase

There is need for continuous, all-weather radionavigation service in the coastal area to provide, at the least, the position fixing accuracy to satisfy minimum safety requirements for general navigation. These requirements are delineated in Table 2-4. Furthermore, the total navigational service in the coastal area must provide service of useful quality and be within the economic reach of all classes of mariners. It should be sufficient to assure that no boat or ship need be lost or endangered, or that the environment and public safety not be threatened, because a vessel could not navigate safely with reasonable economic efficiency.

Requirements: Requirements on the accuracy of position fixing for safety purposes in the coastal phase are established by:

- The need for larger vessels to navigate within the designated one-way traffic lanes at the approaches to many major ports, in fairways established through offshore oil fields, and at safe distances from shallow water.

- The need to define accurately, for purposes of observing and enforcing U.S. laws and international agreements, the boundaries of the Fishery Conservation Zone, the U.S. Customs Zone, and the territorial waters of the U.S.

Minimum Performance Criteria: Government studies have established that a navigation system providing a capability to fix position to an accuracy of 0.25 nm will satisfy the minimum safety requirements if a fix can be obtained at least every 15 minutes. As a secondary economic factor, it is required that relatively higher repeatable accuracy be recognized as a major advantage in the consideration of alternative candidate radionavigation systems for the coastal area. As indicated in Table 2-4, these requirements may be relaxed slightly for the recreational boat and other small vessels.

In such activities as marine scientific research, hydrographic surveying, commercial fishing, and petroleum or mineral exploration, as well as in Navy operations, there may be a need to establish position in the coastal area with much higher accuracy than that needed for safety of general navigation. In many of these special operations which require highly accurate positions, the use of radiodetermination would be classified as radiolocation rather than radionavigation. As shown in Table 2-4, the most rigid requirement of any of this general group of special operations is for seismic surveying with a repeatable accuracy on the order of 1 to 100 meters (2 drms), and a fix rate of once per second for most applications.

2.4.4 Ocean Phase

The requirements for safety of navigation in the ocean phase for all ships are given in Table 2-5. These requirements must provide the Master with a capability to avoid hazards in the ocean (e.g., small islands, reefs) and to plan correctly the approach to land or restricted waters. For many operational purposes, repeatability is necessary to locate and return safely to the vicinity of a maritime distress, as well as for special activities such as hydrography, research, etc. Economic efficiency in safe transit of open ocean areas depends upon the continuous availability of accurate position fixes to enable the vessel to follow the shortest safe route with precision, minimizing transit time.

Requirements: For safe general navigation under normal circumstances, the requirements for the accuracy and frequency of position fixing on the high seas are not very strict. As a minimum, these requirements include a predictable accuracy of 2 to 4 nm coupled with a maximum fix interval of 2 hours or less. These minimum requirements would permit reasonably safe oceanic navigation, provided that the navigator understands and makes allowances for the probable error in navigation, and provided that more accurate navigational service is available as land is approached. While these minimum requirements would permit all vessels to navigate with relative safety on the high seas, more desirable requirements would be predictable accuracy of 1 to 2 nm and a fix interval of 15 minutes or less. The navigation signal should be available 95 percent of the time. Further, in any 12-hour period, the probability of obtaining a fix from the system should be at least 99 percent.

Larger recreational craft and smaller commercial fishing vessels which sail beyond the range of coastal navigation systems require, for a reasonable level of safety, some means of establishing their position reliably at intervals of a few hours at most. Even more so than with larger ships, this capability is particularly important in time of emergency or distress. Many operators of these craft, however, will accept the risk of ocean sailing without reliable radionavigation unless that capability is available at relatively low cost.

Minimum Performance Criteria: Economic efficiency in transoceanic transportation, special maritime activities and safety in emergency situations require or benefit from navigational accuracy higher than that needed for safety in routine, point-to-point ocean voyages. These requirements are summarized in Table 2-5. The predictable accuracy requirements may be as stringent as 10 meters for special maritime activities, and may range to 0.25 nm for large, economically efficient vessels, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nm. As indicated in Table 2-5, the required fix interval may range from as low as once per 5 minutes to as high as once per minute. Signal availability must be at least 95 percent and approach 99 percent for all users.

2.4.5 Future Marine Radionavigation Requirements

The marine radionavigation requirements presented in the preceding discussions and tables are based on a combination of requirements studies, user inputs, and estimates. However, they are the product of current technology and operating practices, and are therefore subject to revision as technologies and operating techniques evolve. The principal factors which will impact future requirements are safety, economics, energy conservation, environment, and evolving technologies.

Special radionavigation requirements may arise from new environmental laws and regulations designed to reduce marine vessel casualty events. Also, the role of commercial ships in military sealift missions may require additional navigation systems capabilities.

Safety:

A. Increased Risk from Collision, Grounding, and Ramming

Hazardous cargoes (petroleum, chemicals, etc.) are carried in great volumes in U.S. coastal and inland waterways. Additionally, the ever increasing volume of other shipping and the increasing numbers of smaller vessels act to constantly increase the risk of collision, grounding, and ramming. Economic constraints also cause vessels to be operated in a manner which, although not unsafe, places more stringent demands on all navigation systems.

B. Increased Size and Decreased Maneuverability of Marine Vessels

The desire to minimize costs and to capture economies of scale in marine transportation have led to design and construction of larger vessels and unitized tug/barge combinations, both of which are relatively less powerful and maneuverable than their predecessors. Consequently, improved navigational performance is needed.

C. Greater Need for Traffic Management/Navigational Surveillance Integration

The foregoing trends underlie the importance of continued governmental involvement in marine vessel traffic management to assure reasonable safety in U.S. waters. Radionavigation systems may become an essential component of traffic management systems. Differential GPS is expected to play an increasingly important role in such areas as VTS.

Economics:

A. Greater Congestion in Inland Waterways and Harbor/Harbor Approaches

In addition to the safety penalty implicit in greater congestion in restricted waterways, there are economic disadvantages if shore facilities are not used effectively and efficiently. Accurate radionavigation systems can contribute to better productivity and decreased delay in transit.

B. All Weather Operations

Low visibility and ice-covered waters presently impede full use of the marine transportation mode. Evolving radionavigation systems may eventually alleviate the impact of these restrictions.

Environment: As onshore energy supplies are depleted, resource exploration and exploitation will move further offshore to the U.S. outer continental shelf and to harsher and more technically demanding environments. In addition, more intensive U.S. fishing activity is anticipated as the result of legislative initiatives and the creation of the U.S. Fishery Conservation Zone. In summary, both sets of activities may generate demands for navigational services of higher quality and for broadened geographic coverage in order to allow environmentally sound development of resources.

Energy Conservation: The need to conserve energy resources and to reduce costs provides powerful incentives for increased transportation efficiency, some of which could come from better navigation systems.

2.5 Civil Land Radionavigation User Requirements

Requirements for use of radionavigation systems for land vehicle navigation are being developed. Many civil land applications for radionavigation systems are currently being investigated, and vehicular radionavigation systems are being tested by state and Federal government agencies and private industry. Radionavigation systems for automatic vehicle location, automated vehicle monitoring, and automated dispatch have already been fielded. Also, several tens of thousands of radionavigation receivers are estimated to be in use by land vehicles in the U.S. in general transportation, emergency services, and the transportation of hazardous materials. Many of these receivers are installed on trucks that engage in interstate commerce.

A variety of space and terrestrial radio communications systems is used to communicate between the vehicles and the control or dispatch sites. Vehicle onboard status of system and fuel consumption to determine allocation of fuel taxes are among the types of information that can be communicated along with position.

ITS operational tests are continuing and it is clear that large scale deployment will include a number of navigation mechanisms and they will most likely be shared with other systems and services. For example, several ITS operational tests use GPS, which is already being shared with numerous other systems and communities, along with radiobeacon systems and other radiolocation systems. Such an approach for sharing brings benefits of more efficient use of the scarce radio frequency spectrum as well as reduction of capital cost of infrastructure and related operations, administration and maintenance costs.

While civil land applications for radionavigation systems appear to be concentrated in the transportation community, electronic chart development, receiver miniaturization, and cost reduction are leading to development of portable land navigators for the camper or backwoods sports enthusiast.

There is also considerable interest in using DGPS for various surveying functions.

Requirements: The navigation accuracy, availability, and integrity requirements of land modes of transportation as well as security requirements associated with radionavigation systems (including continuity of service) have been documented in the December 1993 *Report of the Joint DOD/DOT Task Force, The Global Positioning System: Management and Operation of a Dual* Use *System.* Highway requirements contained in the document are in the process of being validated under DOT contract. The accuracy requirements listed in Table 2-6 will be reviewed for reasonableness and applicability to the ITS program.

Table 2-6. Land Transportation Positioning/Navigation System Accuracy Requirements

Highways:	**Meters**
Navigation and route guidance	5-20
Automated vehicle monitoring	30
Automated vehicle identification	30
Public safety	10
Resource management	30
Accident or emergency response	30
Collision avoidance	1
Geophysical survey	5
Geodetic control	Submeter
Rail:	**Meters**
Position location	10-30
Train control	1
Transit:	**Meters**
Vehicle command and control	30-50
Automated voice bus stop annunciation	25-30
Emergency response	75-100
Data collection	25-35

A special case exists for the railroads, which are privately owned with the individual companies maintaining their right-of-ways, terminals, and rail equipment. While the railroads have not adopted GPS for traffic management or train control, they have conducted studies identifying the GPS augmentation criteria needed to support their operations. Those criteria will be included in requirements validation studies.

Integrity requirements for ITS functions are dependent on resolution of final system architecture issues, which are under study at this time. Values will probably range between 1 and 15 seconds, depending on the function. GPS will most likely not be the sole source of positioning data for collision avoidance systems, since the distance separations needed are in the order of meters. GPS may be used for speed and direction checking, reducing integrity requirements to the same range as for other ITS functions.

Integrity needs for rail use are 5 seconds for most functions. Those for transit are under study and are not available at this time. Availability for all functions, highways, transit and rail, is estimated as 99.7 percent.

While the Government has no statutory responsibility to provide radionavigation services for land radionavigation applications or for non-navigation uses, their existence and requirements are recognized in the Federal radionavigation systems planning process. Accordingly, the Government will attempt to accommodate the requirements of such users.

2.6 Requirements for Surveying, Timing, and Other Applications

Use of radionavigation systems for applications other than navigation is well-established in some fields and is rapidly increasing. While there may be many diverse uses, the majority fall into the following categories:

- Radiolocation: Using radionavigation systems signals for surveying and site registration; noting the location of a place or event for record purposes, or returning to it at a later time.
- Time/Frequency Dissemination: Using radionavigation system signals to accurately time nonassociated electronic systems.
- Meteorological Applications: Using radionavigation signals to support meteorological operations; namely, to track balloon-borne weather radiosondes and dropwindsondes released from weather reconnaissance aircraft.
- Tracking Applications: Tracking of goods for regulatory or commercial purposes.

Many non-navigation uses for radionavigation systems have developed over the years. Previous government studies and inputs from users had given a preliminary indication of such usage, and the extent of these non-navigation uses was emphasized at the FRP user conferences and Federal interagency meetings. These uses include wildlife migratory studies, forestry conservation, communications and power network timing systems, and site registration systems. Requirements for surveying, timing, and other uses are listed in Table 2-7.

Table 2-7. Requirements for Land Use, Surveying, Timing and Other Applications

Surveying

TASK	MINIMUM PERFORMANCE CRITERIA: Accuracy - 1 Sigma, Position, Absolute(m) Horizontal	Absolute(m) Vertical	Relative (cm) Horizontal	Relative (cm) Vertical	Coverage %	Availability %	Interval: Measurement Recording (seconds)	Interval: Solution Fix	Remarks
STATIC SURVEY	0.3	0.5	1.0	2.0	99	99	5	30 min.	O-25km
GEODETIC SURVEY	0.1	0.2	1.0	2.0	99	99	5	4 hrs.	0 - 6000 km
RAPID SURVEY	0.3	0.5	2.0	5.0	99	99	1	5 min.	O-20km
"ON THE FLY" KINEMATIC SURVEY	0.3	0.5	2.0	5.0	99	99	0.1 - 1.0	0.1 - 1 .0 sec.	O-20km Real Time

Timing and Other Applications

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS: ACCURACY (2 dnms) PREDICTABLE	ACCURACY (2 dnms) REPEATABLE	ACCURACY (2 dnms) RELATIVE	COVERAGE	AVAILABILITY	FIX INTERVAL	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY
COMMUNICATIONS NETWORK SYNCHRONIZATION		1 part in 10 (freq)*	-	Nationwide	99.7%	Continuous	N/A	Unlimited	N/A
SCIENTIFIC COMMUNITY		1 part in 10 (freq)	-	Worldwide	99.7%	Continuous	N/A	Unlimited	N/A
METEOROLOGY	Velocity 1 m/sec				TBD	TBD	TBD		TBD
POWER NETWORK SYNCHRONIZATION		1ms"	-	North America	99.7%	1 second	Two	Unlimited	Resolvable with 99.9% confidence

* Proposed ITU Standard based on American Telephone and Telegraph "Stratum 1 Requirement".

* * At any substation. 8ms (1/2 cycle) systemwide.

In addition to its space and aeronautics applications, NASA has requirements for the use of GPS in the monitoring of earth crystal dynamics. NASA sponsored the development of the International GPS Service (IGS) for Geodynamics and operates the data collection and analysis facilities which provide data products for use in a number of international geodynamic research efforts.

2.6.1 *Geodesy and Surveying*

The geodetic survey community has been an important user of radionavigation signals since 1957.

Although this community of users has historically concentrated on determining the geodetic coordinates of a survey geodetic monument, it has gone well beyond that -particularly with the advent of GPS. Today the geodetic user of radionavigation signals might be interested in the trajectory of an aircraft for a photogrammetric or gravimetric mission or in the precise trajectory of a satellite such as TOPEX/POSEIDON. The hydrographic surveyor might have a few-centimeter positioning requirement and a meter-level navigation requirement.

Since 1980, the geodetic surveyor has used the GPS carrier phase signals, both Ll and L2, to measure baseline vectors to the centimeter-level of accuracy and occasionally to the millimeter level. Today, surveyors routinely measure 5, 50, 500, and 5000 km baselines to centimeter accuracy in all components. The geodetic community has carried out considerable research and development and has developed models and methods that both the navigation and geodetic communities routinely use. As an example, the geodetic survey community developed the kinematic GPS survey methods which have quickly been adopted for precision navigation and positioning by the navigation community.

GPS is also increasingly used in the development of geographic information systems (GIS).

2.6.2 *Timing/Frequency Offset Applications*

There are currently no definitive statements of the requirements for timing and frequency offset applications. One national telephone company uses Loran-C and GPS extensively for communication network synchronization. It is estimated that a worldwide GPS ground network may be able to provide clock synchronization to better than one nanosecond and relative determination to one part in 10^{14}. These clock calibrations will be useful for deep space tracking and at astrophysical observatories. Several power companies are experimenting with GPS for measuring phase differences between major power transmission stations and substations, for event recording, for post-disturbance analysis, and for measuring the relative frequency of power systems.

2.6.3 Meteorological Applications

It is estimated that the international meteorological community launches several hundred thousand weather radiosondes and dropwindsondes a year worldwide to measure such atmospheric parameters as pressure, temperature, humidity, and wind speed and direction. Current technology uses Omega and Loran-C radionavigation signals to track the airborne instrument package and to measure wind speed and direction; however, research and development in the use of GPS is being pursued.

2.7 Space Radionavigation Requirements

Several programs conducted or supported by NASA are evaluating GPS for spacecraft position determination. TOPEX/POSEIDON, launched on August 10, 1992, is using a high-accuracy dual-band GPS flight receiver on an experimental basis. Based on successful experiments conducted on the Space Shuttle and on the TOPEX/POSEIDON and EUVE instrumented satellites, NASA is planning to implement GPS as an operational system on many future missions.

Planned and proposed future NASA spacecraft will require continued use of GPS.

- The International Space Station (ISS) is being designed to implement GPS for navigation, attitude determination, and Universal Time distribution. GPS will support onboard ISS system control functions as well as various experimenter data capture processes.
- The Space Shuttle will implement GPS for all three mission phases by 1998. GPS has been flight tested on various Shuttle missions and studies are being conducted to determine the extent of future cost savings that can be realized by replacing current ground facility functions with the automatic onboard GPS support.
- Two small satellite programs recently initiated by NASA to explore low cost access to space will implement GPS for navigation, time, and attitude determination functions. The use of low cost onboard GPS receivers for these basic functions may become a significant factor in providing inexpensive access to space for both future NASA and commercial small satellite projects.
- Where scientific data position accuracy is required with precision greater than that readily available from the GPS receiver onboard a spacecraft, a refinement of post-pass orbit data will be used. NASA has developed post-pass orbit data processing techniques using GPS on the TOPEX/POSEIDON satellite that provides accuracy at the 5 cm level. In order to accomplish this, some internal receiver parameters must be available for downlink with the science data.

- GPS tracking is being used by the NASA Deep Space Network (DSN) to improve knowledge of the Earth's pole position and speed of rotation. The use of GPS for this purpose is making a significant reduction in demand for measurements with deep space antennas. The centimeter level accuracy available with GPS tracking for geocentric correction to deep-space antenna coordinates is significantly improving the deep-space tracking error budget.

The use of GPS for space applications fall into two basic categories:

1. Onboard spacecraft vehicle navigation support where GPS will be used in near real-time applications for navigation and attitude determination. In this role, onboard navigation and attitude accuracy requirements are:

   - Three-dimensional position error not to exceed 20 m (1 sigma).
   - Three-dimensional velocity error not to exceed 0.1 m/sec (1 sigma).
   - Attitude determination error not to exceed 0.1 degree in each axis (1 sigma).
   - Clock offset error between coordinated universal time (UTC) and onboard receiver time not to exceed 1 microsecond (1 sigma).

2. Scientific data analysis support where GPS will be used to accurately locate instrument position in space when measurements are taken. Current accuracy requirements are to determine three dimensional position within 5 cm. However, more accurate positioning in the 1 to 2 cm range may be required in the future for some earth observation instruments. Ground-based post-pass processing techniques are being used today to achieve 5 cm accuracy for the TOPEX/POSEIDON spacecraft instruments and NASA is continuing to refine this technique to realize the higher accuracy levels in the future.

2.8 Military Radionavigation Requirements

Military forces must be prepared to conduct operations anywhere in the world, in the air, on and under the sea, on land, and in space. During peacetime, military platforms must conform to applicable national and international rules in controlled airspace, on the high seas, and in coastal areas. Military planning must also consider operations in hostile environments.

2.8.1 General Requirements

Military navigation systems should have the following characteristics:

- Worldwide coverage.

- User-passivity.
- Capability of denying use to the enemy.
- Support of unlimited number of users.
- Resistance to spoofing (imitative navigational signal deceptions), interference, jamming, and intrusion.
- Resistance to natural disturbances and hostile attacks.
- Effectiveness of real-time response.
- Availability for combined military operations with allies.
- Freedom from frequency allocation problems.
- Use of common grid for all users.
- Position accuracy that is not degraded by changes in altitude for air and land forces or by time of year or time of day.
- Accuracy when the user is in high "G" or other violent maneuvers.
- Maintenance by operating level personnel.
- Continuous availability for fix information.
- Non-dependence on externally generated signals.

The ideal military positioning/navigation system should be totally self-contained so that military platforms are capable of performing all missions without reliance on information from outside sources. No single system or combination of systems currently in existence meets all of the approved military navigation requirements. No known system can provide a common grid for all users and at the same time be passive, self-contained, and yield the worldwide accuracies required. The nature of military operations requires that essential navigation services be available, with the highest possible confidence that these services will equal or exceed mission requirements. This, among other considerations, necessitates a variety of navigational techniques and redundant installations on the various weapon system platforms for military operations. Currently, the DOD is unable to conduct some military missions with the precision and accuracy demanded without some aid from external radionavigation systems. However, there has been significant progress in the development of reliable self-contained systems (inertial systems, Doppler systems, geomagnetic navigation, and terrain/bottom contour matching).

While the survivabihty of any radionavigation system is scenario-dependent, in almost any scenario the GPS is considered more survivable than other systems because:

- Moving transmitters in space are less vulnerable than ground-based transmitters.
- Spread spectrum transmission techniques protect against jamming.
- Anti-spoofing is available.
- Transmitters are hardened against electromagnetic pulse (EMP).

Loran-C coverage is limited when viewed from a worldwide perspective, and six of the eight Omega transmitters are located in areas not controlled by the United States.

While reliance on a single POS/NAV system is unwise, redundant or backup systems for military operations should not be more vulnerable, less-capable external systems. Rather, DOD must invest in reliable, accurate, self-contained systems that are uniquely tailored to match platform mission requirements. Therefore, the DOD POS/NAV architecture will be based upon GPS, which provides accurate worldwide positioning, velocity and time, backed by modem, accurate, and dependable self-contained systems.

2.8.2 Service Requirements

The CJCS MNP provides specific DOD requirements for navigation, positioning, and timing accuracy organized by primary missions and functions with specifically related accuracy requirements. These requirements are used for information and guidance in the development and procurement of military navigation systems.

3

Radionavigation System Use

This section summarizes the plans of the Federal Government to provide general-purpose and special-purpose radio aids to navigation for use by the civil and military sectors. It focuses on three aspects of planning: (1) the efforts needed to maintain existing systems in a satisfactory operational configuration; (2) the development needed to improve existing system performance or to meet unsatisfied user requirements in the near term; and (3) the evaluation of existing and proposed radionavigation systems to meet future user requirements. Thus, the plan provides the framework for operation, development, and evolution of systems.

The Government operates radionavigation systems which meet most of the current and projected civil user requirements for safety of navigation, promotion of reasonable economic efficiency, and positioning and timing applications. These systems are adequate for the general navigation of military craft as well, but none completely satisfies all the needs of military missions or provides highly accurate, three-dimensional, worldwide navigation capability. GPS satisfies many of these general and special military requirements. GPS has broad potential for satisfying current civil user needs or for responding to new requirements that present systems do not satisfy. It could ultimately become the primary worldwide system for military and civil navigation and position location.

3.1 Existing Systems Used in the Phases of Navigation

It is generally accepted that the needs for navigation services derive from the activities in which the users are engaged, the locations in which these activities occur, the relation to other craft and physical hazards and, to some extent, the type of craft. Because these differences exist, navigation services are divided by classes or types of users and the phases of navigation. These divisions are summarized in Tables 3-l through 3-3. These tables also show current application of the existing radionavigation systems in the various phases of navigation. Detailed descriptions of the existing and proposed radionavigation systems are given in Appendix A.

The systems listed in Table 3-l are used singly or in combination to support functions of the various phases of civil navigation. Tables 3-2 and 3-3 compare common-use systems to mission applications for military use. Table 3-4 provides estimates of the current numbers of users of Federally provided radionavigation systems. The following sections describe the approach employed to define the needs, requirements, and degree to which existing systems satisfy user needs.

3.1.1 Air Navigation

VOR/DME forms the basis of a safe, adequate, and trusted international air navigational system, and there is a large investment in ground equipment and avionics by both the Government and users. In view of this, it is intended to maintain the VOR/DME system at its present capability for a reasonable transition period after augmented GPS is approved as a primary navigation system. The current ICAO protection date extends to January 1, 1998.

As evidenced by user conferences and aircraft equipage, there is increasing interest and usage of GPS and Loran-C for air navigation. Both systems are certified as supplemental systems. In 1994, unaugmented GPS was also approved as a primary system for use in oceanic and remote airspaces. The GPS WAAS, which is scheduled to be implemented in 1997, is expected to be certified as a primary navigation system. This will allow termination of many existing ground-based radionavigation aids after an adequate transition period to allow users to equip with WAAS avionics.

Oceanic En Route: Oceanic en route air navigation is currently accomplished using inertial reference system/flight management computers, inertial navigation systems (INS), Omega, Loran-C, GPS, or a combination of these systems. Use of Doppler and celestial navigation is still approved. Use of VOR/DME, TACAN, and Loran-C is approved where there is adequate coverage.

Domestic En Route: Domestic en route air navigation requirements are presently being met, except in some remote and offshore areas. The basic short-distance aid to navigation in the U.S. is VOR alone, or collocated with either DME or TACAN to form a VOR/DME or a VORTAC facility. This system is used for en route and terminal navigation for flights conducted under Instrument Flight Rules. It is also used by pilots operating under Visual Flight Rules. The U.S. and all other member states of ICAO have agreed to provide VOR/DME service to international air carriers up to January 1, 1998. Loran-C, Omega, and inertial systems are also used for domestic en route navigation. When inertial systems are used, their performance must be monitored through the use of an approved externally referenced radio aid to navigation. Loran-C and GPS both are approved as supplemental systems. GPS is

Table 3- 1. Civil Radionavigation System Applications

MODE	SYSTEMS							
	LORAN-C	OMEGA	VOR/DME	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS	AUG-MENTED GPS
AIR								
EN ROUTE/TERMINAL								
Remote Areas	X	X	E	-		X	X	X
Special Helicopter	X	E	E	-		X	X	X
Oceanic En Route	X	x	-				X	X
Domestic En Route	X	X	X			X	X	X
Terminal	X		X		-	X	X	X
AIRPORT SURFACE	-		-					E
APPROACH/LANDING								
Nonprecision	X	X	x	-		X	X	X
Precision				X				X
MARINE								
Ocean	X	x	-		X	X	x	-
Coastal	x	-				X*	X	X
Harbor & Harbor Approach					-	X*	-	X
Inland Waterways								X
LAND								
Navigation	X	X		X	X	X	X	X
SPACE								
Navigation/Tracking						X	X	X
Terminal Approach			-			-	X	X
Terminal Landing				x	-		X	X
OTHER								
AVM/AVL	X	x	-		-		X	X
Site Registration							X	X
Surveying							X	X
Timing/Frequency	x	x	-		-		X	X
Meteorology	X	X					X	X

LEGEND

X ***Current or Planned Application***
E ***System in Evaluation***
\- System Not Used
***** **Includes Racons**

Table 3-2. DOD Radionavigation System Applications

USAF AND ARMY AVIATION MISSIONS	SYSTEM								
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS	AUG. MENTED GPS
EN ROUTE									
Foreign									
Domestic			X	x	-	-	X	x	-
Domestic			X	x	-		X	x	-
Combat	Theatre		-	X			X	X	
Overwater		x	-					x	-
Remote Area	x	x	-				X	x	-
TERMINAL			X	x	-		X	X	-
APPROACH/ LANDING									
Nonprecision	-		X	x	-	-	X	X	E
Precision Landing					x	-		X	E
SPACE									
Launch/Abort			-	X	x	-	-	x	-
Orbital						-		x	-
Re-Entry						-		x	-
SURVEYING								X	E
TARGET ACQUISITION				x	-	-	X	x	-
AERIAL RENDEZVOUS				x	-	-	X	x	-

LEGEND

X Current or Planned Application
E ***System in Evaluation***
- System Not Used
* ***Includes Racons***

Table 3-2. DOD Radionavigation System Applications (Cont.)

NAVAL MISSIONS	SYSTEM								
	LORAN-C	OMEGA	VOR/DME	TACAN	MLS/ILS	TRANSIT	RADIO-BEACONS	GPS	AUG-MENTED GPS
EN ROUTE, GENERAL PURPOSE									
Ship	X	x	-				X	x	-
Submarine	X	x	-	:	-		-	x	
Air							X	x	
SEARCH & RESCUE									
Ship							-	x	
Air								x	
MINE COUNTER-MEASURES									
Ship	X	)					-	x	
Air				x				x	
MINE LAYING									
Ship	X							X	
Submarine		X						x	
Air		x		x				x	
AMPHIBIOUS WARFARE									
Ship		x					X	x	
Air				x				x	
ANTI-AIR WARFARE									
Ship	X	x						x	
Air				x				X	
SURFACE WARFARE									
Ship	X	x						x	
Submarine	X	x						x	
Air		x		x				x	
ANTISUBMARINE WARFARE									
Ship		x						x	
Submarine		X						x	
Air	X	X	X	X	x		X	X	
LOGISTICS									
surface	X	x						x	
Submarine	X	X						x	
Air	X	X	X	X	x		X	x	
SURVEYING									
surface	X	X						X	
Submarine	X	x						x	
Air	X	X	X	x			X	x	

LEGEND

X Current or Planned Application
E System in Evaluation
\- System Not Used
**** Includes Racons***

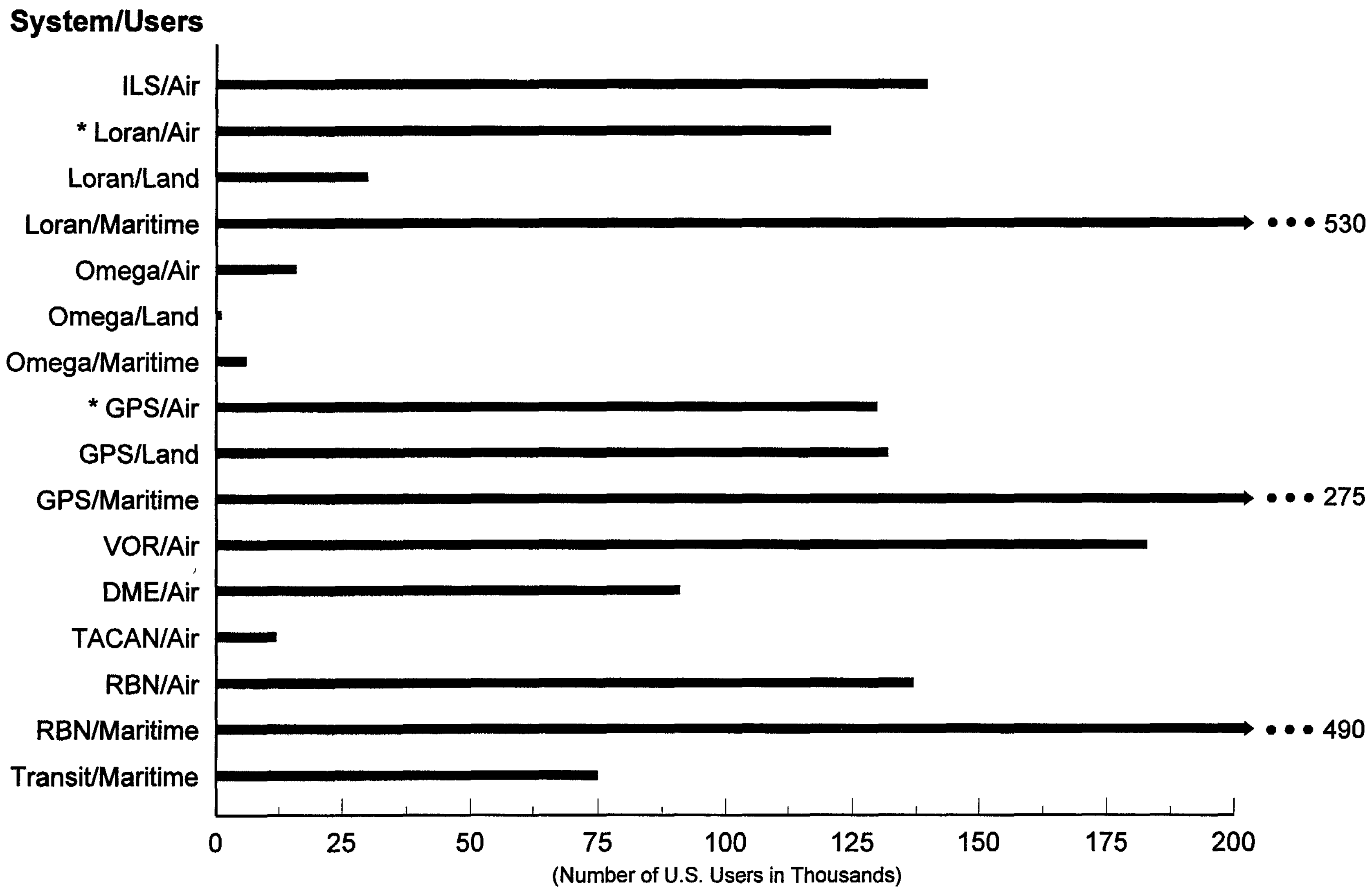
Table 3-3. Defense Mapping Agency Radionavigation System Applications

Applkations	SYSTEMS				
	LORAN-C	OMEGA	TRANSIT	GPS	AGPS
WORLDWIDE POSITIONING OF SATELLITE (ORBITAL TRACKING)					
Low Altitude				x	-
Medium Altitude				x	-
High Altitude				x	-
GEODETIC POSITIONING BY SATELLITE (RELATIVE)				x	-
GEODETIC POSITIONING (CONVENTIONAL)				x	-

LEGEND

X Current or Planned Application
- System Not Used

Table 3-4. Estimated Current Radionavigation System User Population



* Includes a large number of receivers that are not certified for IFR use, including handheld receivers

also approved as a primary system for use in remote areas, and can be used to provide separation between aircraft in accordance with current DME standards.

Terminal: Terminal air navigation requirements are presently met using VOR, VOR/DME, VORTAC, TACAN, NDB, GPS, or Loran-C. Loran-C and GPS are approved as supplemental systems.

Approach and Landing: Nonprecision approach navigation requirements are presently met using ILS localizer, VOR, VOR/DME, VORTAC, TACAN, GPS, Loran-C, or NDB. Loran-C and GPS are approved as supplemental systems. Precision approach and landing requirements are presently met by ILS (Categories I,II, and III) and MLS (a limited number of Category I systems only).

3.1.2 Marine Navigation

Marine navigation comprises four major phases: inland waterway, harbor/harbor approach, coastal, and oceanic. The phase of navigation in which a mariner operates determines which radionavigation system or systems will be the most useful. While some radionavigation systems can be used in more than one phase of marine navigation, the most promising system to meet the most stringent requirements of the harbor/harbor approach and inland waterway phases of marine navigation is differential GPS. With regard to the coastal phase of navigation, DGPS will provide the navigational features currently being met by Loran-C as it is used in the repeatable mode of navigation.

Inland Waterway Phase: This phase of navigation is concerned primarily with those vessels which are not oceangoing. Specific quantitative requirements for navigation on rivers and other inland waterways have not yet been developed. Visual and audio aids to navigation, radar, and intership communications are presently used to enable safe navigation in those areas. However, the potential for differential GPS to play an increasing role in this phase of navigation is possible. Loran-C coverage of the‘48 conterminous states provides some capability, but without integrating the use of Loran-C into another system such as DGPS, it alone does not meet the requirements of inland waterways navigation.

Harbor/Harbor Approach Phase: Navigation in the harbor/harbor approach areas is accomplished through use of fixed and floating visual aids to navigation, radar, and audible warning signals. The growing desire to reduce the incidence of accidents and to expedite movement of traffic during periods of restricted visibility and ice cover has resulted in the implementation of VTS and investigation of the use of radio aids to navigation. The differential GPS system is anticipated to meet the navigational needs for this phase of navigation, but it will be necessary to integrate it with an electronic chart display information system (ECDIS).

The USCG plans to install DGPS for harbor/harbor approach navigation. The coverage will include all coasts of the continental U.S. and parts of Alaska, Hawaii, and the Great Lakes. The system will be complete by the end of 1996 and will provide between 2 and 20 meter accuracy.

Coastal Phase: Requirements for operation within the coastal area are now fully met by Loran-C, which was fully implemented by 1980, as well as by the Navy's Transit system. GPS now also meets these needs.

Radiodirection Finders (RDF), required in some merchant ships by international agreement for search and rescue purposes, are also used with the radiobeacon system for navigation.

Ocean Phase: Navigation on the high seas is accomplished by the use of dead-reckoning, celestial fixes, self-contained navigation systems (e.g., inertial systems), Loran-C, Omega, Transit, and GPS. GPS reached its Initial Operational Capability (IOC) on December 3, 1993, and is now the system of choice for this phase of marine navigation. Worldwide coverage by most ground-based systems such as Loran-C is not practicable. The Omega system, however, with all eight stations operational, does provide essentially worldwide coverage.

3.7.3 Land Navigation

GPS and Loran-C are used in land vehicle navigation, although the Government does not have a specific responsibility under law to provide radionavigation systems for civil land use. However, under the general provisions for improving the safety and efficiency of transportation, a number of projects have been sponsored by government and industry to evaluate the feasibility of using existing and proposed radionavigation systems for land navigation. Many land navigation applications are being developed, while others are beyond the developmental stage, particularly in Intelligent Transportation Systems applications. For example, operational tests have been completed that use in-vehicle navigation systems and electronic mapping systems to provide real-time traffic information to drivers. Loran-C has been used for automatic vehicle location for bus scheduling. Operational tests are either planned or in progress to use radionavigation for route guidance, in-vehicle navigation, providing real-time traffic information to traffic information centers, and improving emergency response. Several transit operational tests will use automatic vehicle location for automated dispatch, vehicle re-routing, schedule adherence, and traffic signal pre-emption. Examples include the use of Loran-C for vehicle location and dispatch. Loran-C, GPS, and dead-reckoning map-matching are being developed as systems that could take advantage of radionavigation systems and at the same time improve safety and efficiency of land navigation.

Although most operational tests plan to use GPS as the primary source of vehicle location information, other viable alternatives include microwave and infrared beacons, triangulation from broadcast stations, and vehicle location using cellular radio transmissions.

3.1.4 Uses Other Than Navigation

These uses are concerned primarily with the application of GPS, Loran-C, and Omega for radiolocation and surveying, time and frequency dissemination, and meteorological upper-air observations. Many other uses of GPS and augmented GPS are anticipated for Federal, state, and local governments, industry, and consumers. As with land navigation, the Government does not have a responsibility under law to provide radionavigation systems for these users. However, these applications represent a large (and growing) percentage of the civil radionavigation user community.

3.1.5 Space Navigafion

There are numerous uses of GPS for space navigation; many are discussed in Section 2.7. Several spacecraft, including the International Space Station, the Space Shuttle, TOPEX/POSEIDON, ARISTOTELES, and the small satellites Lewis and Clark are using or will be using GPS for navigation. Some of these spacecraft will use GPS for support of instrument pointing, scientific data processing, and, in the case of the Space Shuttle, during approach and landing as well as on orbit and during ascent.

3.2 Existing and Developing Systems - Status and Plans

3.2. I Loran-C

Loran-C was developed to provide military users with a radionavigation capability having much greater coverage and accuracy than its predecessor (Loran-A). It was subsequently selected as the Federally provided radionavigation system for civil marine use in the U.S. coastal areas. It is now designated by the FAA as a supplemental system in the NAS.

A. Operating Plan

Loran-C was designated as the Federally provided navigation system for the U.S. coastal areas in 1974. Implementation of the program authorized at that time has been completed. Studies have shown that further expansion is not cost-beneficial. The domestic Loran-C system as it is operated and supported by the USCG as of January 1, 1995 will consist of 29 transmitting stations comprising 12 Loran-C chains. Included in this count is the Russian-American chain and the East Newfoundland Loran-C chain. The former is a joint chain operated with Russia; the latter is a Canadian chain which was developed to return Loran-C to portions of the area previously covered by the Labrador Sea chain.

Current use of the Loran-C system appears to be leveling off and will most likely decrease as GPS and DGPS equipment fills the market place. This trend is expected to continue unless user equipment is developed that will take advantage of the two systems; i.e., Loran-C and GPS have no common vulnerabilities as they would apply to jamming, spoofing and interference. However, given the expected decrease in use, the estimated time frame for continued need of Loran-C in the U.S. has been reduced to the year 2000. Accordingly, the USCG has suspended its Loran-C equipment recapitalization program. The remaining initiatives include replacement of older transmitters in Alaska, the introduction of the automatic blink system, and consolidating the control of Loran-C. It remains unclear at this time if any equipment changes necessary to automate the synchronization of Master stations to UTC will be implemented.

Figure 3-l outlines the operating plan for the Loran-C system. The coverage is shown in Appendix A.

B. User Community

Initially, the major user of Loran-C was the military, since civil marine use was limited due to the high cost of Loran-C receivers and the lack of coverage over much of the U.S. coastal areas. Technological advances rapidly lowered user receiver costs, and coastal coverage limitations have been eliminated by system improvements and expansion. As a result, there is presently extensive civil marine and aviation use of Loran-C. In addition, there is growing terrestrial use in radiolocation, vehicle tracking, and precise time/time interval and frequency applications. The meteorological community uses Loran-C based upper air observation systems.

C. Acceptance and Use

Up to the present, users of Loran-C have been one of the largest communities employing a single radionavigation system. This situation is changing now that GPS has achieved initial operational capability and GPS user equipment continues to drop in price. Traditionally, the primary users of Loran-C were the maritime community operating in the coastal phase and, in certain parts of the world, in the oceanic phase of marine navigation. In the few years preceding the expansion of Loran-C to the mid-continent regions of the United States, the aviation, time and frequency and terrestrial uses of Loran-C became recognized. Use of the system is expected to remain constant with little to no growth anticipated in the near term. As existing Loran-C user equipment becomes outdated, it is anticipated that users will purchase GPS, or augmented GPS equipment and begin the transition away from Loran-C.

D. Outlook

Other countries are developing and continuing Loran-C to meet their future navigational needs. Many of these initiatives have taken place as a result of the termination of the U.S. DOD requirement for overseas Loran-C. This need came to an end as of December 31, 1994. With the introduction of GPS, many countries have decided that it is in their own best interests not to have their navigational needs met entirely by a U.S. DOD-controlled navigation system. To preclude a potential situation (real or perceived) where GPS could be further degraded to meet U.S.

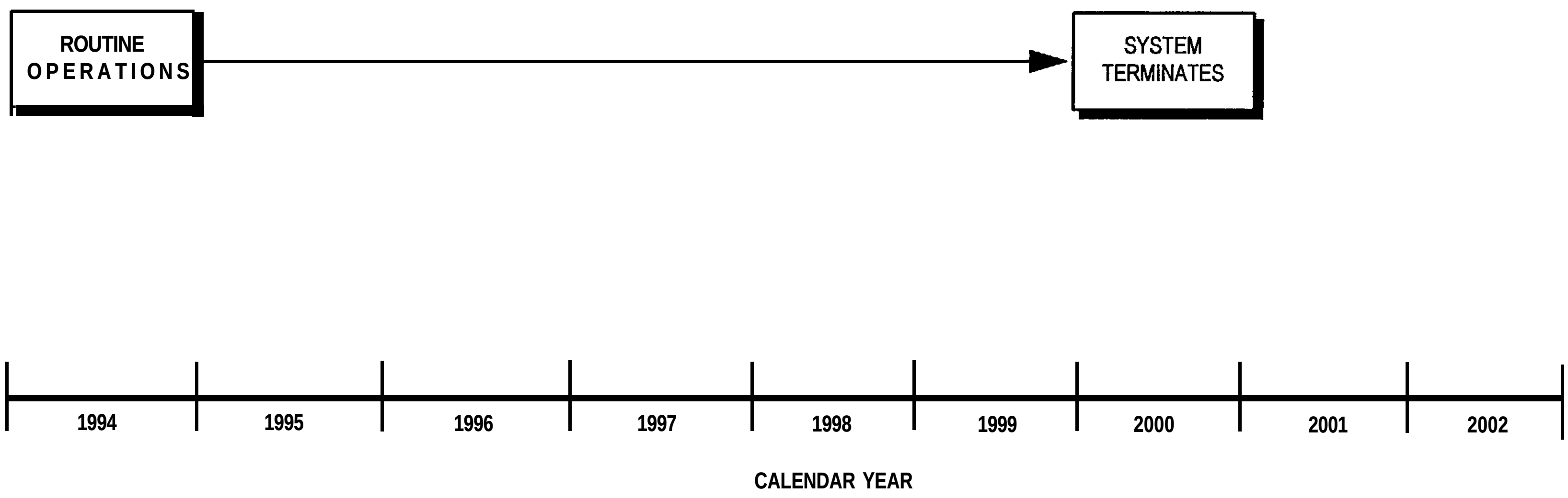


Figure 3-1. Operating Plan for Loran-C

defense objectives, these countries have opted to take on the responsibility to continue Loran-C,

Many of these initiatives have resulted in multilateral agreements between countries which have common navigational interests in those geographic areas where Loran-C previously existed to meet U.S. DOD requirements (e.g., Northern Europe, the Mediterranean and the Far East). In each of these cases, Russia has taken a significant interest in continuing its work for the integration into future chains of its Loran-C equivalent (Chayka). The IALA is taking a key role in facilitating the planned expansion of Loran-C in each of these areas. In Europe, the European Union has endorsed Loran-C as the terrestrial system of choice for maritime use into the next century.

Other nations which have their own loran chains are France (in the rho-rho or ranging mode), the People's Republic of China, Saudi Arabia, and India. It is projected that by January 1,1995, there will be a total of 34 Loran-C chains covering much of the terrestrial and surrounding maritime regions of the Northern Hemisphere.

3.2.2 Omega

The Omega system was developed and implemented by the Department of the Navy, with the assistance of the USCG and with the participation of several partner nations. It provides worldwide, all-weather radionavigation capability to air and surface users. The U.S. responsibility for operation of the system rests with the USCG.

A. Operating Plan

The eight-station Omega configuration has been operational since August 1982, although, in earlier configurations, the system was widely used for more than five years before this date. Omega stations are located in Norway, Liberia, North Dakota, Hawaii, La Reunion Island, Argentina, Australia, and Japan. The USCG operates the two stations located in the U.S. Bilateral agreements between the U.S. and the partner nations govern partner-nation operation, and the varying amounts of technical and logistic support. The USCG has operational control of the system; the International Omega Technical Commission (IOTC), which is composed of one representative from the operating agency of each country involved with the Omega system, is the forum for consultation regarding operational maintenance of Omega. Figure 3-2 outlines the operating plan for the Omega system.

B. User Community

In addition to the DOD air and marine users, civil ships and aircraft are using the Omega system. A number of air carriers and general aviation aircraft operators have received approval to use Omega as an update for their self-contained systems or as a primary means of navigation on oceanic routes. Receiver innovations have led to the use of very low frequency (VLF) communications transmissions to augment the

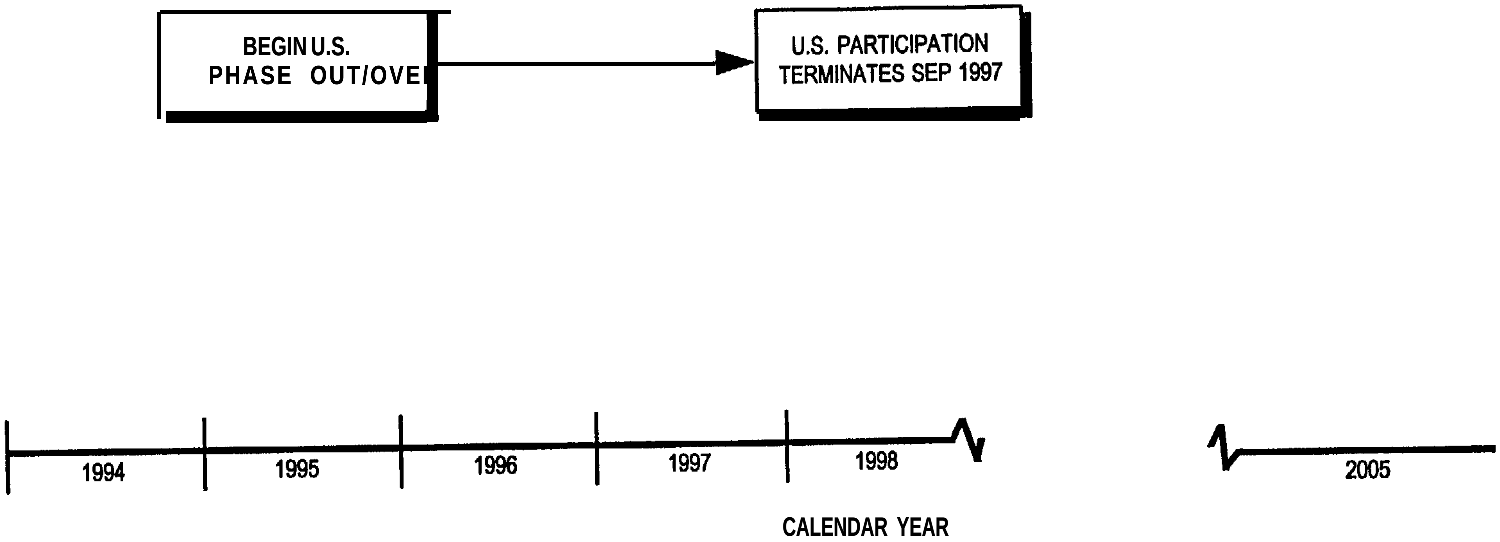


Figure 3-2. Operating Plan for Omega

Omega network and improve overall system redundancy and reliability; however, the U.S. Navy has emphasized that VLF communication signals are not intended for navigation purposes and that the use of these signals for navigation is at the risk of the user. Receivers designed to use VLF communication signals as part of the navigation solution should be capable, using Omega signals only, of meeting performance standards contained in FAA Advisory Circular 20- 101 C and Technical Standard Order TSO-C 120.

Guidelines for the transmission of differential Omega corrections were established by the Inter-governmental Maritime Consultative Organization (now known as the International Maritime Organization - IMO) in Resolution A.425 (XI), "Differential Omega Correction Transmitting Stations," dated November 15, 1979.

C. Acceptance and Use

Because of its worldwide coverage, international civil use of Omega includes trans-oceanic shipping and aircraft navigation. It is also approved by the FAA for use as a supplement for domestic high altitude en route airspace navigation.

The precise timing aspects of Omega make it possible to obtain profiles of wind speed and direction from ground level to over 30 km with an Omega-based meteorological upper-air observation system. Over 200,000 Omega-equipped meteorological sondes are launched annually from approximately 550 locations around the world.

Current information indicates that the present Omega system covers nearly 100 percent of the Earth's surface. Signal coverage and system accuracy have been validated on a regional basis. The data collected from 22 fixed monitor receiver sites, shipboard monitor receivers, and aircraft receivers are being used to correct propagation models and tables and to confirm propagation parameters affecting signal coverage and availability. Results obtained from the validation effort have shown that the Omega system is meeting published performance. Validations began in the mid- 197Os, and have been completed in the North Atlantic, North Pacific, South Atlantic, South Pacific, and Indian Oceans as well as the Mediterranean Sea. Accuracy of the Omega system is limited due to signal propagation characteristics and restrictions on signal selection when in close proximity to transmitting sites. For these reasons, Omega does not meet navigation requirements for vessels in U.S. coastal waters, or for aircraft flying in U.S. terminal airspace.

D. Outlook

Replacement of the timing and control equipment at transmitting stations is in progress. Other efforts are focused on, and dominated by, the transmitting antennas, particularly those in Hawaii and Norway. In addition, the USCG continues to improve user services and system performance. This includes coverage prediction programs, propagation models, and signal timing synchronization efforts.

Because of the international character of the system and international user acceptance, operational decisions regarding system life must be coordinated with the partner nations. The DOD requirement terminated in 1994, however, limited Service use is expected while the system remains operational and receiver maintenance is cost effective. For example, in response to a Congressional mandate, the U.S. Air Force Reserve's 53rd Weather Reconnaissance Squadron will continue to use an Omega-based dropwindsonde system to provide hurricane reconnaissance observations in support of the hurricane warning responsibilities of the National Weather Service's National Hurricane Center-a Department of Commerce activity.

With the achievement of GPS IOC in December 1993, the approval of GPS to meet aviation requirements currently met by Omega is imminent. It is anticipated that aviation users will quickly transition from Omega to GPS due to its accuracy and rapidly dropping equipment prices. Mariners are already using GPS for oceanic navigation. Because the U.S. navigation needs for Omega will be met by GPS, and Omega use is declining rapidly, continuation of U.S. participation in Omega beyond September 30, 1997 will depend on the financial support of the system by timing and weather users. The Government of Australia has projected that it will terminate operations at its Omega station on September 30,1997.

3.2.3 VOR and VOR/DME

VOR was developed as a replacement for the Low-Frequency Radio Range to provide a bearing from an aircraft to the VOR transmitter. A collocated DME provides the distance from the aircraft to the DME transmitter. At most sites, the DME function is provided by the TACAN system which also provides azimuth guidance to military users. Such combined facilities are called VORTAC stations. Some VOR stations are used for the scheduled broadcast of weather information.

A. Operating Plan

The FAA operates 10 12 VOR, VOR/DME, and VORTAC stations including 150 VOR-only stations. The number of stations is expected to remain stable until the VOR/DMEs begin to be decommissioned in 2005. The DOD also operates stations in the U.S. and overseas that are available to all users. The operating plan for VOR and VOR/DME is shown in Figure 3-3.

B. User Community

Approximately 85 percent of general aviation aircraft are equipped with at least one VOR receiver and over 50 percent of the aircraft have two or more VOR receivers. All air carrier aircraft depend on it for bearing information. DME is used to provide distance information for all U.S. air carrier aircraft and for a large number of general aviation and military aircraft operating in U.S. airspace.

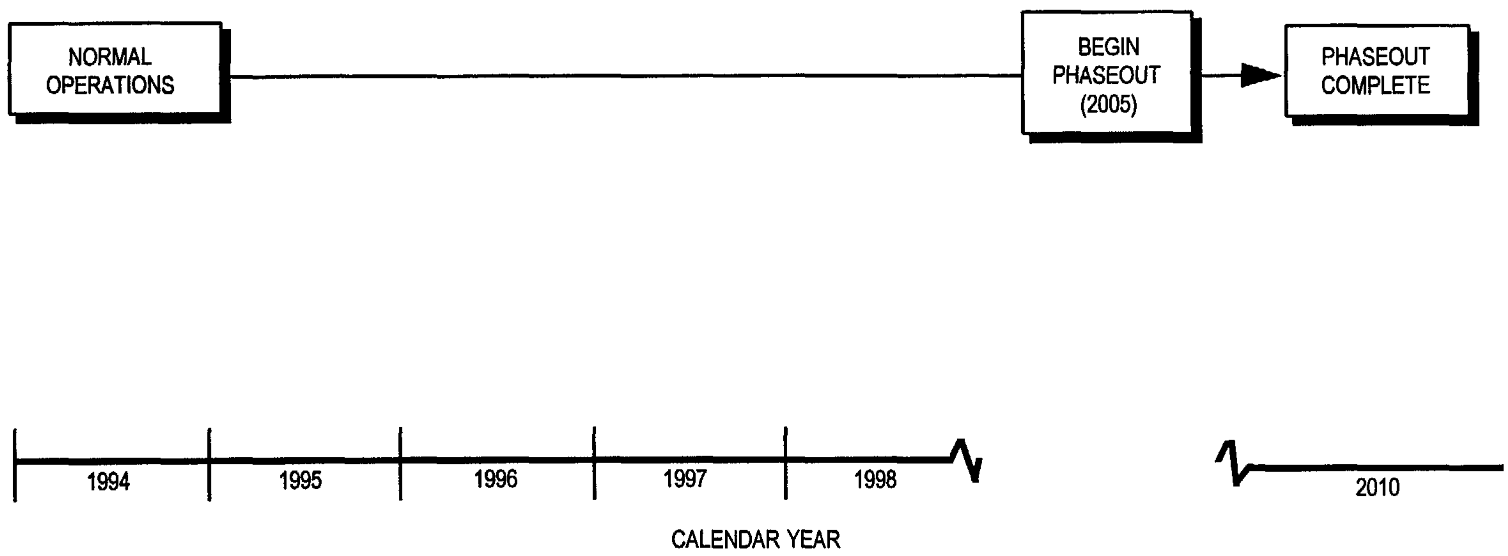


Figure 3-3. Operating Plan for VOR and VOR/DME (Based on GPS/WAAS Operational Date)

C. Acceptance and Use

VOR is the primary radionavigation aid in the National Airspace System and is the internationally designated standard short-distance radionavigation aid for air carrier and general aviation IFR operations. It is easy to use and is generally liked by pilots. Because it forms the basis for defining the airways, its use is an integral part of the air traffic control procedures.

D. Outlook

A small increase in the number of users equipped with VOR is expected over the next several years due to an increase in the aircraft population operating in the U.S. During this time, many users that are equipping their aircraft for VFR operation may choose to equip with GPS in preference to VOR. VOR/DME will still be required for IFR flight until the WAAS is approved for primary means navigation. It is then expected that VOR equipage will begin to rapidly decrease.

The current VOR/DME network will be maintained until 2005 to enable aircraft to become equipped with WAAS avionics and to allow the aviation community to become familiar with the system. Plans for expansion of the network are limited to site modernization or facility relocation, and the conversion of sub-standard VORs to a Doppler VOR configuration. The phaseout of the VOR/DME network is expected to begin in 2005 and to be complete by 2010.

The target date for phase-out of the DOD requirement for VOR and VOR/DME is the year 2000. In the case of a military VORTAC site that has developed an appreciable civilian-use community and is due for phase-out, transfer of operational responsibility to the DOT will be discussed between DOD and DOT.

3.2.4 TACAN

TACAN is a UHF radionavigation system which provides a pilot with relative bearing and distance to a beacon on the ground, a ship, or to specially equipped aircraft. TACAN is the primary tactical air navigation system for the military services ashore and afloat. TACAN is often collocated with the civil VOR stations (VORTAC facilities) to permit military aircraft to operate in civil airspace.

A. Operating Plan

DOD presently operates 173 TACAN beacons and the FAA operates 640 TACAN beacons for DOD. Present TACAN coverage ashore will be maintained until phased out in favor of GPS. However, GPS without enhancement cannot replace the TACAN function afloat (moving platforms). Civil DME and the distance-measuring functions of TACAN will continue to be the same. The operating plan for TACAN is shown in Figure 3-4.

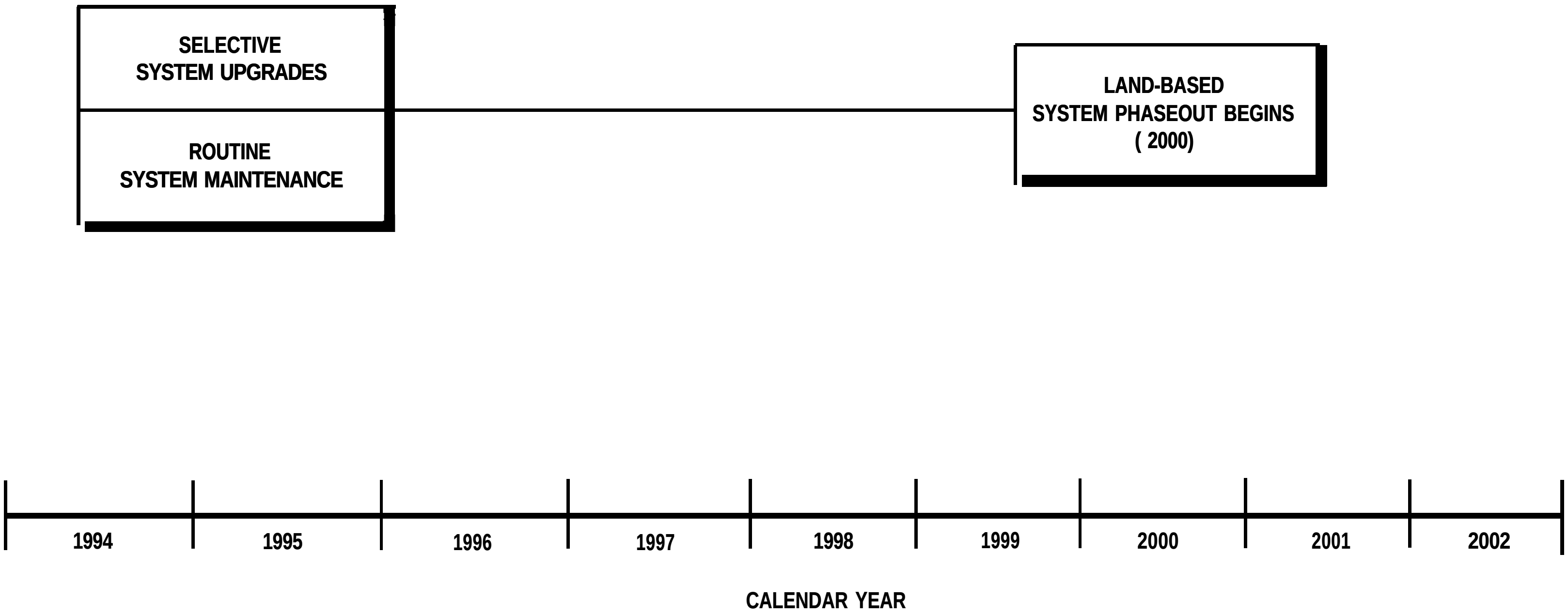


Figure 3-4. Operating Plan for TACAN

B. User Community

There are presently approximately 14,500 aircraft which are equipped to determine bearing and distance to TACAN beacons. These consist primarily of Navy, Air Force, and to a lesser extent, Army aircraft. Additionally, allied and third world military aircraft use TACAN extensively. NATO has standardized on TACAN until 1995.

C. Acceptance and Use

TACAN is used by DOD and NATO aircraft operating under IFR ashore and IFR and VFR for tactical and en route navigation afloat. TACAN provides range and azimuth information and is easy to use.

Because of propagation characteristics and radiated power, TACAN is limited to line-of-sight and is limited to approximately 180 miles at higher altitudes. As with VOR/DME, special consideration must be given to location of ground-based TACAN facilities, especially in areas where mountainous terrain is involved due to its line-of-sight coverage.

D. Outlook

The DOD requirement for and use of land-based TACAN will terminate when aircraft are properly integrated with GPS and when GPS is certified to meet RNP in national and international controlled airspace. Any decommissioning of TACAN facilities will take place by mutual agreement between FAA and DOD. The target date to begin phaseout of TACAN services is 2000. The DOD plans to complete GPS integration by 2000. In order to satisfy projected RNP criteria, some current DOD GPS user equipment will require modification. The expected completion date for this modification effort is no later than 2005. The requirement for shipboard TACAN will continue until a suitable replacement is operational.

3.2.5 ILS

ILS provides aircraft with precision vertical and lateral navigation (guidance) information during approach and landing. Associated marker beacons or DME equipment identify the final approach fix, the point where the final descent to the runway is initiated.

A. Operating Plan

The FAA operates nearly 900 ILS systems in the NAS, of which 81 are Category II or Category III systems. In addition, the DOD operates 165 ILS facilities in the U.S. New ILS sites may be installed prior to the availability of precision approaches using the WAAS if they are cost-beneficial. The operating plan is shown in Figure 3-5.

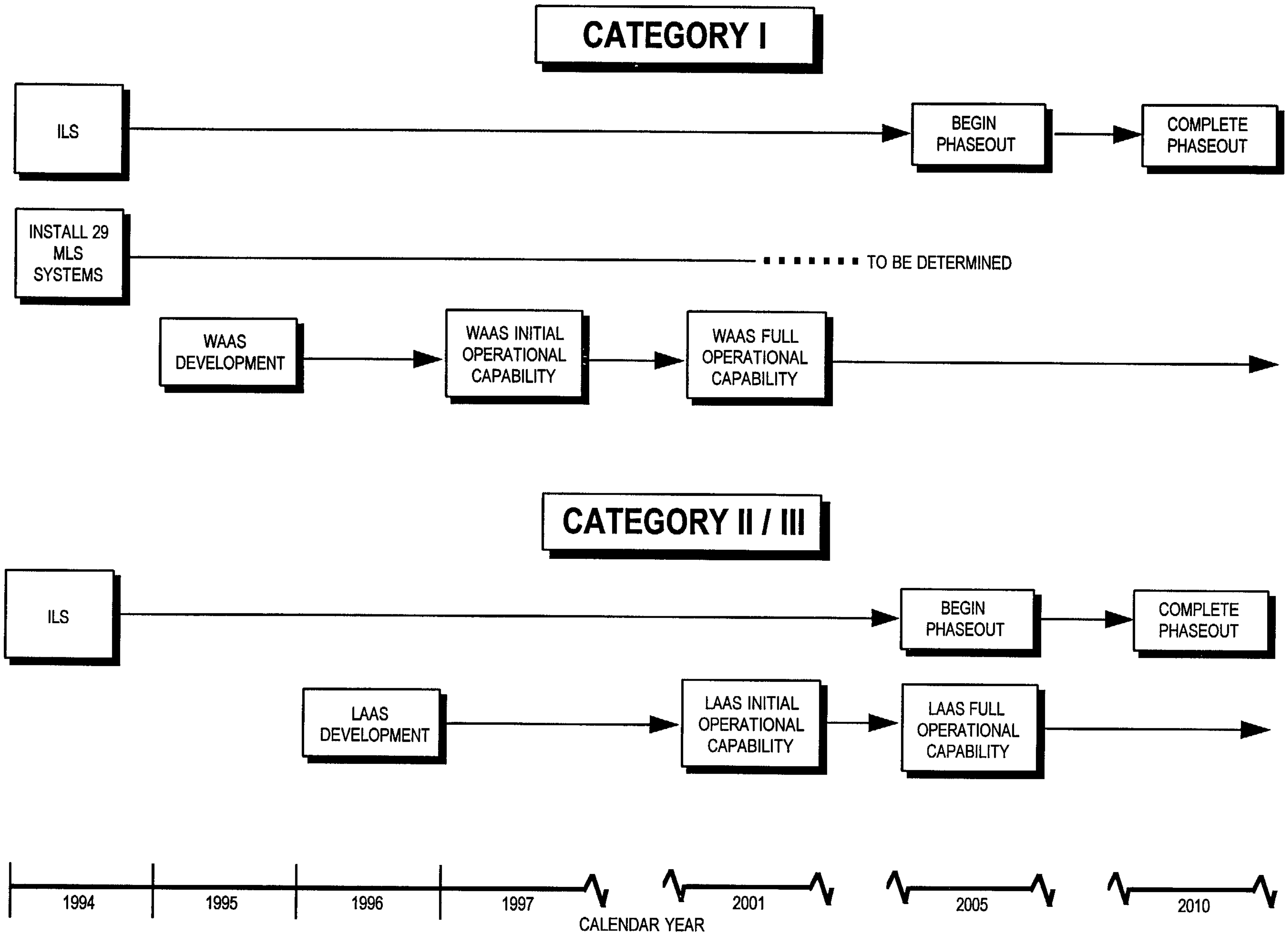


Figure 3-5. Operating Plan for Precision Landing Systems

B. User Community

Federal regulations require US. air carrier aircraft to be equipped with ILS avionics. It is also extensively used by general aviation aircraft. Since ILS is the ICAO standard landing system, it is extensively used by air carrier and general aviation aircraft of other countries.

C. Acceptance and Use

A slight increase in the number of users equipped with ILS is expected over the next several years due to an increase in the aircraft population operating in the U.S. ILS equipage rates are then expected to rapidly decrease once the WAAS is approved for Category I approaches.

D. Outlook

User Base Expansion: Based on a 1991 user survey, the number of civil aircraft equipped with ILS is estimated to be 124,000. This number is expected to increase until the GPS WAAS becomes operational and gains user acceptance.

Expected System Life: ILS is the standard civil landing system in the U.S. and abroad, and is protected by ICAO agreement to January 1, 1998. ICAO has selected the MLS as the international standard precision approach system, with implementation targeted for 1998. The U.S. will continue to work with ICAO Member States to review the ICAO ILS/MLS transition plan in light of new technologies. This transition plan will be revisited at ICAO's Special Communications/Operations Divisional Meeting scheduled for March 1995. The FAA will provide the latest results of its R&D efforts on the use of satellite technology for precision approaches and landing at that meeting.

ILS will remain the primary system for Category I precision approaches until 2001 when the WAAS is expected to be designated as a primary Category I service. ILS will remain in service together with WAAS precision approaches to allow users an opportunity to equip with WAAS receivers and to become comfortable with its service. The phaseout of Category I ILS is expected to begin in 2005 and to be complete by 2010.

For Category II/III precision approaches, test results show that a GPS-based system promises to deliver this level of service in a more cost-effective manner than ILS. Because of these results, the first GPS-based Category II/III systems are anticipated to be introduced into the NAS by 2001, collocated at existing Category II/III sites. The phaseout of Category II/III ILS from the NAS is then expected to begin in 2005 and to be complete by 2010.

System Limitations: ILS limitations manifest themselves in three major areas:

1. Performance of individual systems can be affected by terrain and man-made obstacles, e.g., buildings and surface objects such. as taxiing aircraft and snowbanks. These items may impose permanent use constraints on individual systems or limit their use at certain times.

2. The straight-line approach path inherent in ILS constrains airport operations to a single approach ground track for each runway. In contrast, both GPS and MLS will allow multiple ground track paths for approaches to the active runway as well as provide a steeper glide slope capability for Short Take-Off and Landing (STOL) aircraft.

3. Even though the new 50 kHz frequency spacing has doubled the ILS channel availability, frequency saturation limits the number of systems that can be installed. Frequency saturation occurs when ILS facilities, in close proximity with inadequate frequency separation, produce mutual interference.

3.2.6 MLS

A limited procurement of Category I MLS equipment was initiated in 1992. However, the FAA has determined that augmented GPS is feasible for Category I precision approach operations and is progressing toward implementation and certification. Only 29 Category I MLS systems are currently planned to be installed, and the FAA has terminated the development of Category II and III MLS equipment.

The termination of the Category II and III development contracts was primarily a budget decision, supported by initial results of R&D efforts that have demonstrated the potential for using augmented GPS technology for this application. The FAA retains the option to purchase MLS for Category II and III operations on the open market should the decision be made to implement MLS in the future.

A. Operating Plan

The operating plan for the 29 Category I MLS systems is shown in Figure 3-5.

B. User Community

MLS applications are limited to aviation. The U.S. does not plan at this time to install MLS except where required by treaty.

C. Acceptance and Use

MLS does not have the siting problems of ILS and offers higher accuracy and greater flexibility, permitting precision approaches at more airports. MLS provides DOD tactical flexibility due to its ease in siting and adaptability to mobile operations. However, there is limited user support for MLS in the U.S.

D. Outlook

Unless required by treaty, little use of MLS is anticipated in the U.S.

3.2.7 Transit

The Navy Navigation Satellite System (NNSS), also referred to as Transit, is a satellite-based positioning system which provides submarines, surface ships, and a few specially equipped aircraft with an accurate two-dimensional positioning capability. The Transit system consists of low-altitude satellites in near polar orbits, ground-based monitor stations to track the satellites, and injection facilities to update satellite orbital parameters.

Developed to support the Navy Fleet Ballistic Missile Submarines, Transit is now installed on domestic and foreign commercial vessels in addition to military surface vessels.

A. Operating Plan

DOD plans to operate Transit until December 1996. Ground-based monitor and injection facilities and satellites will be operated and supported by the Navy.

The current Transit constellation contains seven satellites. Five satellites are operational and two satellites are stored in orbit.

The Transit launch program ended in 1988. The Navy will terminate operation of the system by the end of 1996. The operating plan is shown in Figure 3-6.

B. User Community

There are currently fewer than 200 military Transit users. Foreign and domestic commercial vessel use of the Transit system has far outpaced the DOD use. It is estimated that 80,000 sets were in commercial use at the end of 1987. Approximately 90 percent of all commercial Transit receiver sales are for the single channel receivers. Determination of precise position (surveying) has become an important use of Transit.

C. Acceptance and Use

Transit provides periodic, worldwide, position-fixing information for Navy ships and submarines and commercial ships, as well as land users. Use of Transit has declined in recent years due to the advent of GPS.

From a military viewpoint, Transit provides precise positioning for fixed and low dynamic vehicles (ships, submarines, and surveying). In a high dynamic, tactical environment (aircraft and missiles), Transit has little use since it is a Doppler system and small errors in user estimates of platform speed can cause large errors in user position. (One knot of unknown speed can cause a position error of 0.2 nm.)

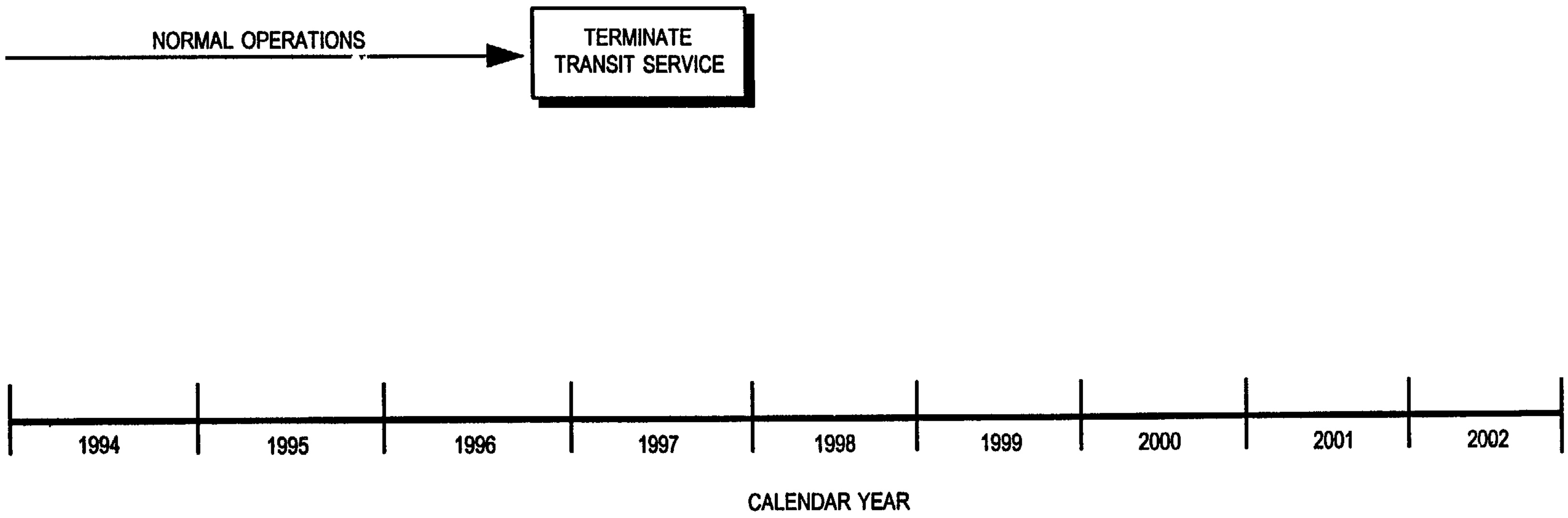


Figure 3-6. Operating Plan for Transit

D. Outlook

Transit will be replaced with GPS by 1996. Transit will not be operated by or transferred to a civilian agency of the U.S. Government.

3.2.8 Aeronautical Nondirectional Beacons (NDBs)

Aeronautical nondirectional beacons are used for transition from en route to precision terminal approach facilities and as nonprecision approach aids at many airports. In addition, some state and locally owned NDBs are used to provide weather information to pilots. In Alaska and in some remote areas, NDBs are also used as en route facilities. However, GPS and the FAA's automated weather observing system (AWOS) and automated surface observing system (ASOS) have begun to satisfy the requirement for NDBs.

A. Operating Plan

The FAA operates over 700 NDBs. This number is expected to decline steadily over the next decade due to the increasing popularity of GPS. In addition, there are about 200 military aeronautical beacons and 800 non-Federally operated aeronautical beacons. During the next 10 years, FAA expenditures for beacons are planned to be limited to the replacement of deteriorated components, modernization of selected facilities, and an occasional establishment or relocation of an NDB used for ILS transition. The operating plan is shown in Figure 3-7.

B. User Community

All air carrier, most military, and many general aviation aircraft carry automatic direction finders (ADF). However, the importance of ADF is expected to decline with the increasing popularity of GPS.

C. Acceptance and Use

Aircraft use radiobeacons as compass locators to aid in finding the initial approach point of an instrument landing system as well as for nonprecision approaches at low traffic airports without convenient VOR approaches.

The large number of general aviation aircraft that are equipped with radio direction finders attests to the wide acceptance of radiobeacons by the user community. The primary reason for this acceptance is that adequate accuracy can be achieved with low-cost user equipment. However, now that GPS-based nonprecision approaches are available, transition from the NDB network can begin.

D. Outlook

GPS today provides improved navigation service compared to NDBs at an acceptably low cost to the user. Therefore, the phaseout of NDBs is planned to begin in the year

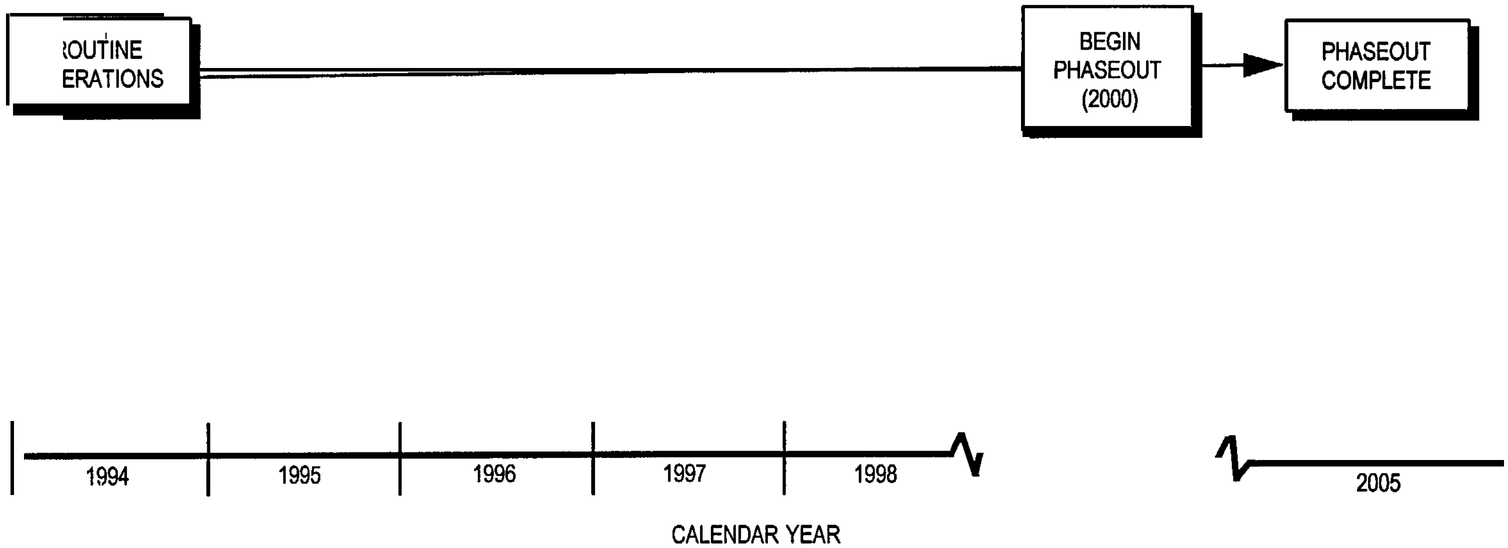


Figure 3-7. Operating Plan for Aeronautical Nondirectional Beacons (Based on GPS/WAAS Operational Date)

2000 and to be complete by 2005. In the interim, Federal expenditures for replacements and new establishments will be limited.

3.2.9 Maritime Radiobeacons

Maritime radiobeacons provide a backup to more sophisticated radionavigation systems and a low-cost, medium accuracy system for vessels equipped with only minimal radionavigation equipment. Use, however, is dwindling very rapidly.

A. Operating Plan

Approximately 85 maritime radiobeacons are operated by the USCG. The operating plan is shown in Figure 3-8. Selected maritime radiobeacons will be modified to broadcast DGPS corrections with the implementation of the USCG DGPS service.

B. User Community

Radiobeacons are primarily used as homing devices for recreational boaters, but they also act as a backup for those users having more sophisticated radionavigation capability. As selected radiobeacons are modified to broadcast DGPS corrections, those radiobeacons will become a primary element in the HHA and coastal phases of navigation, used by all vessels, and required for certain classes of vessels.

C. Acceptance and Use

Maritime radiobeacons have been an acceptable radionavigation tool for pleasure boaters using them for homing purposes, largely due to the adequate service with low-cost user equipment.

Marine radiobeacons provide a bearing accuracy relative to vehicle heading on the order of +3 to +lO degrees. This might be considered a systemic limitation but, in actual use, it is satisfactory for many navigational purposes. Radiobeacons are not satisfactory for marine navigation within restricted channels or harbors. They do not provide sufficient accuracy or coverage to be used as a primary aid to navigation for large vessels in U.S. coastal areas.

D. Outlook

Maritime radiobeacons have been used primarily by pleasure boaters in the homing mode. However, with the availability of low-cost Loran-C and GPS receivers that provide far more flexible use to the boater, the use of radiobeacons has been continually declining. As the USCG conducts evaluation of the need for beacons, those with no identifiable user base will be discontinued. Maritime radiobeacons not modified to carry DGPS correction signals are expected to be phased out by the year 2000.

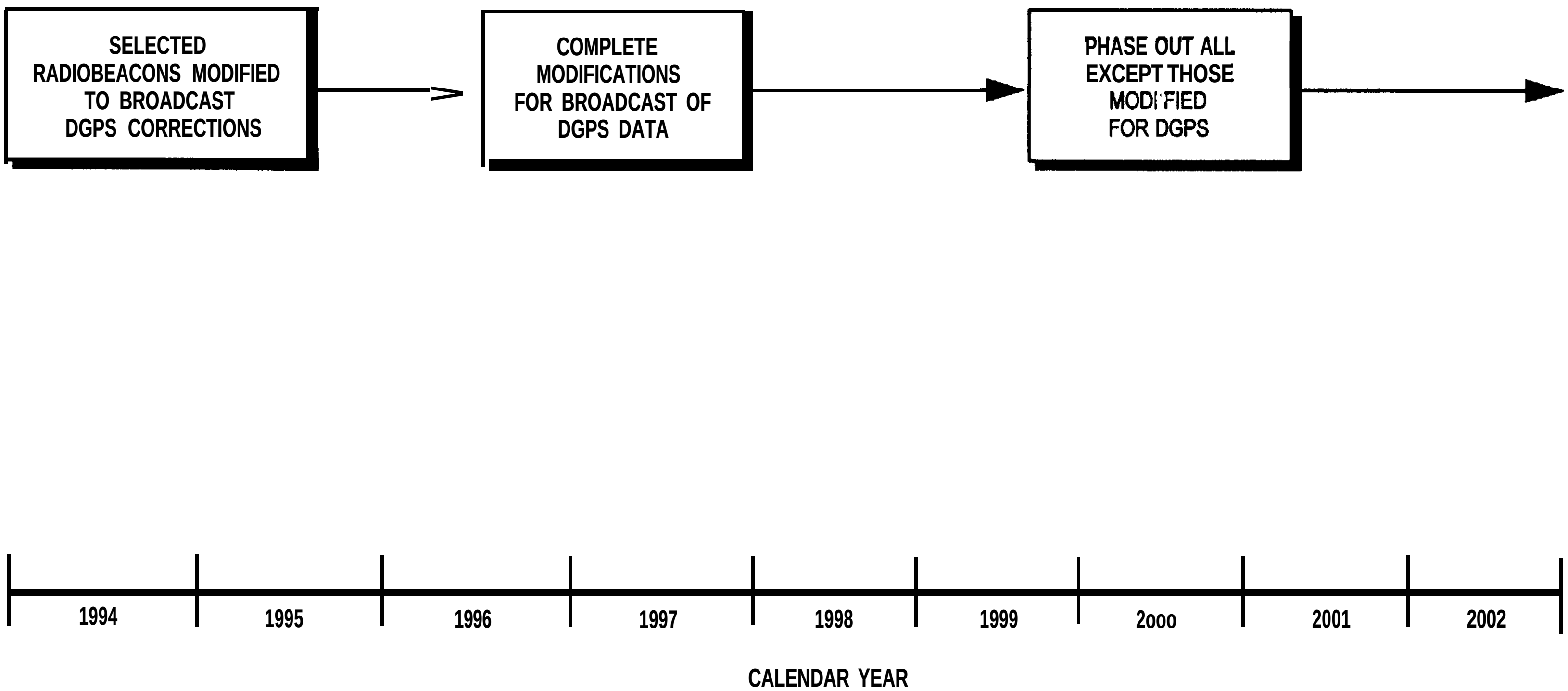


Figure 3-8. Operating Plan for Maritime Radiobeacons

The modulation of maritime radiobeacons with DGPS corrections will make these beacons unusable by digital aviation ADFs and may make their use by analog ADFs difficult.

Radar Transponder Beacons: Radar transponder beacons (RACONs) are short-range radio devices used to provide fixed radar reference points in areas where it is important to identify a special location. Currently, they are only used in the marine environment. Examples of the use of RACONs are: landfall identification; improvement of ranging to and identification of an inconspicuous coastline; improvement of identification of coastlines permitting good ranging but which are otherwise featureless; improvement of the identification of a particular aid to navigation in an area where many radar returns appear on the radar display; provision of a lead to a specific point such as into a channel or under a bridge; and warning to temporarily mark a new obstruction, or other uncharted or especially dangerous fixed hazard to navigation.

Though RACONs offer a unique possibility of positive aid identification, uncontrolled proliferation could lead to an unacceptable increase in responses presented on a ship's radar display. This could degrade the usefulness of the display and cause confusion. In 1986, the Code of Federal Regulations was changed (33 CFR 66.01-I (d)) to allow private operation of RACONs with USCG approval. The USCG now has about 110 frequency agile RACONs.

3.2.10 Global Positioning Sysfem (GPS)

GPS is a space-based positioning, navigation, and time distribution system designed for worldwide military use. Special capabilities of particular interest to DOD include precise, continuous, all-weather, common-grid positioning, velocity and timing. Additionally, the weapon system enhancement features of the GPS can be denied to enemy forces, and the system has features to prevent spoofing and to reduce susceptibility to jamming. Although designed for military use, GPS is available for civil use at the highest accuracy consistent with U.S. national security interests.

A. Operating Plan

GPS will be the primary Federally-funded radionavigation system for the foreseeable future. An Initial Operational Capability (IOC) was declared December 8, 1993 when the DOD determined that the SPS, described in memoranda of agreement between the DOD and DOT, could be sustained. The USCG and FAA subsequently authorized GPS for civil transportation use. DOD Full Operational Capability (FOC) is planned to occur in 1995 after the 24-satellite constellation has completed testing for military functionality (a milestone that does not have any significant impact on civil users).

All routine command and control functions are performed from the Master Control Station in Colorado Springs, Colorado using its dedicated network of remote monitor stations and ground antennas. The GPS constellation is configured and operated to provide the SPS signals to civil users in accordance with *the GPS Standard Positioning Service Signal Specification* (available through the U.S. Government Printing Office and the USCG Navigation Information Service).

The DOD will maintain a 24-satellite constellation. Additional satellites will be launched on an expected failure strategy (an additional satellite is launched when there are indications that a satellite should be replaced).

The operating plan for GPS is shown in Figure 3-9.

B. User Community

The GPS user community has grown exponentially in the past two years and that growth is expected to continue. Rapid growth has occurred in all modes of transportation. Non-transportation use is also growing at a rapid rate and includes users employed in surveying, farming, resource exploration, and law enforcement. Because of security considerations, the GPS Precise Positioning Service (PPS) is restricted to U.S. Armed Forces, U.S. Federal agencies, and selected allied Armed Forces and governments. While GPS/PPS has been designed primarily for military radionavigation needs, it will nevertheless be made available on a very selective basis to U.S. and foreign private sector (non-governmental) civil organizations. Access determinations will be made by the Government on a case-by-case evaluation that:

- Access is in the U.S. national interest.
- There are no other means reasonably available to the civil user to obtain a capability equivalent to that provided by GPS/PPS.
- Security requirements can be met.

The DOT has established the Civil GPS Service (CGS), consisting of the GPS Information Center (GPSIC) (now part of the USCG's Navigation Information Service) and the PPS Program Office (PPSPO). The GPSIC provides information to and is the point of contact for civil users of the GPS system (see Appendix A). The PPSPO administers GPS/PPS service to approved users. Civil users requesting access to the GPS/PPS must submit their applications through the PPSPO. In addition, the DOD and DOT have agreed that representatives from the DOT will be located within the Master Control Station and at the GPS Joint Program Office to participate in the day-to-day system operations, system development, and future requirements definitions.

Any planned disruption of the SPS in peacetime will be subject to a minimum of 48-hour advance notice provided by the DOD to the USCG GPSIC and the FAA Notice to Airman (NOTAM) system. A disruption is defined as periods in which the GPS is not capable of providing SPS as specified in the *GPS Standard Positioning Service Signal Specification.* Unplanned system outages resulting from system

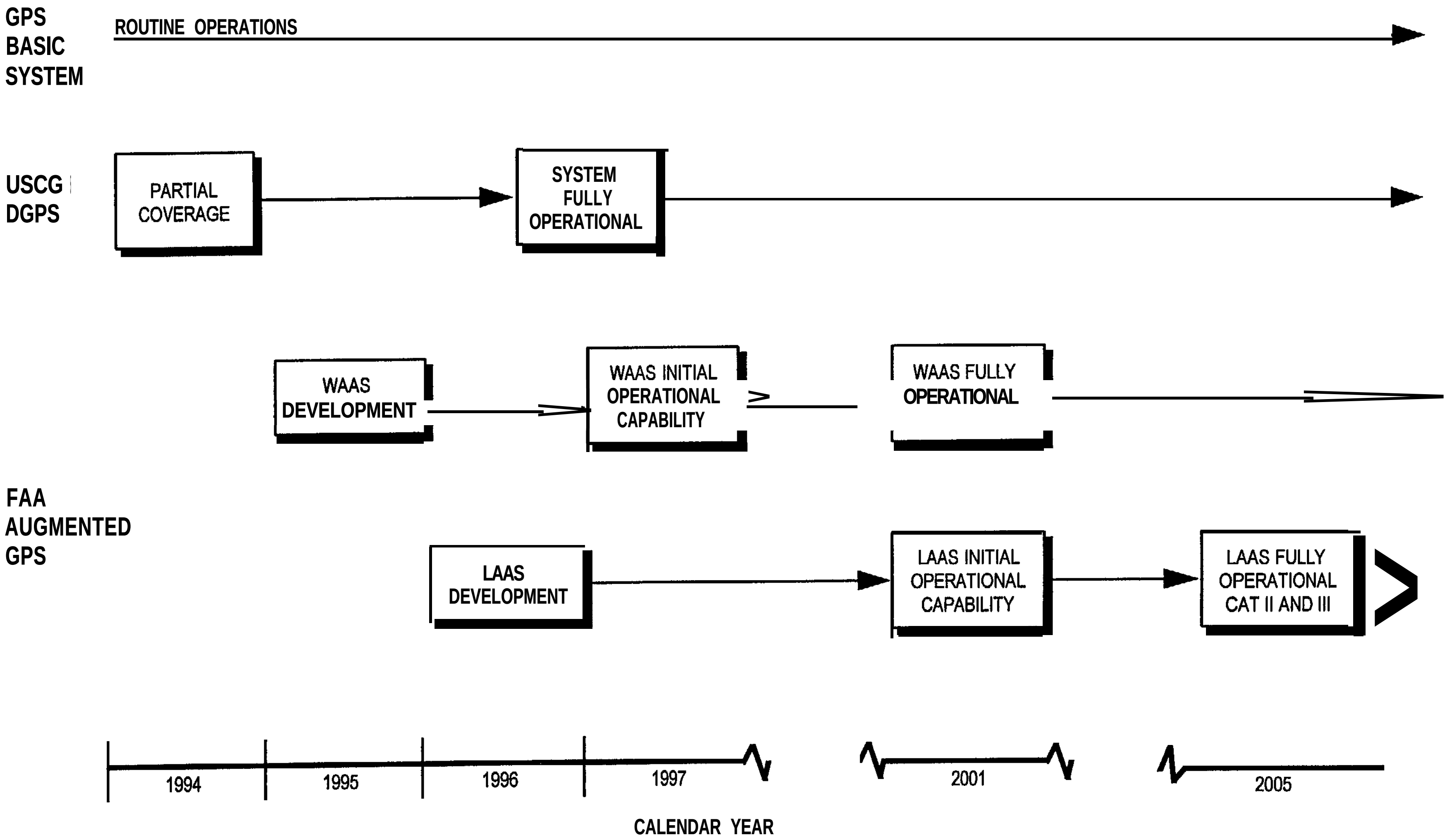


Figure 3-9. Operating Plan for GPS/Augmented GPS

malfunctions or unscheduled maintenance will be announced by the GPSIC and NOTAM systems as they become known.

C. Acceptance and Use

The following list is a sampling of current or likely future uses of GPS as GPS technology replaces earlier less accurate or more costly methods.

Aviation

- Possible future use as a primary means of en route navigation and precision landing and takeoff.
- Current use for supplemental en route navigation.
- Monitor wing deflections in flight.
- Precise location of airfields and landing aids.

Environmental Protection

- Hazardous waste site investigation.
- Ground mapping of ecosystems.
- Oil spill tracking and cleanup.

Highway

- Intelligent Transportation Systems traffic management.
- Highway facility inventory and management.
- Highway construction.
- Navigation for motor vehicle drivers.
- Truck fleet on-the-road management.
- Bus fleet on-the-road management.
- Monitoring status of bridges.

Maritime and Waterways

- Navigation on the high seas.
- Harbor approach navigation.
- Harbor facility management.
- Dredging of harbors and waterways.
- Positioning of buoys and marine nav-aids.
- Navigation for recreational vessels.
- Location of fishing traps and gear.
- Offshore drilling research.
- Monitoring deflections in dams as a result of hydrostatic and thermal stress changes.

Communications

- Precise timing for interlacing messages.

Railroad

- Railroad fleet monitoring.
- Train control and collision avoidance.
- Facility inventory and management.

Surveying

- Use as an electronic bench marker providing absolute geographic reference of latitude, longitude, and altitude.
- Measuring areas without triangulation.
- Oil and mineral prospecting.
- National Spatial Data Infrastructure.

Recreation

- Hiking and mountain climbing.

Law Enforcement and Emergency Response

- Tracking and recovering stolen vehicles.
- Tracking criminal and contraband movements.
- Maintaining security of high government officials and dignitaries while traveling.
- Border surveillance.
- Location identification for ambulance and fire departments.

Weather, Scientific and Space

- For upper-air observation of atmospheric parameters, such as wind speed and direction, pressure, and humidity.
- Measurement of sea level from satellites.
- Navigating and controlling space shuttle.
- Placing satellites into orbit.
- Monitoring earthquake areas and tectonic plate movements.

Agriculture and Forestry

- Forest area and timber estimates.
- Identifying habitats.
- Fire perimeters.
- Water resources.
- Property boundaries.

D. *Outlook*

The basic GPS will be augmented to satisfy remaining transportation requirements, particularly precision approach to aircraft landing and ship harbor operations.

3.2.11 GPS Augmenfufions

Unaugmented GPS will not meet all performance requirements for aviation or for the harbor/harbor approach phase of marine navigation. For example, an aircraft must have at least five satellites in view above a mask angle of 7.5 degrees in order to provide receiver autonomous integrity monitoring (RAIM). This condition is not always satisfied with the existing GPS constellation, resulting in so-called “RAIM holes” and limiting GPS to use as a supplemental navigation system. Some type of augmentation is required for GPS to meet the RNP of an airspace.

GPS may exhibit variances from a predicted grid established for navigation, charting, or derivation of guidance information. This variance may be caused by propagation anomalies, errors in geodesy, accidental perturbations of signal timing, and the implementation **of** SA.

Adverse effects of these variances may be substantially reduced, if not practically eliminated, by differential techniques. In such differential operation, a reference station is located at a fixed point (or points) within an area of interest. GPS signals are observed in real time and compared with signals expected to be observed at the fixed point. Differences between observed signals and predicted signals are transmitted to users as differential corrections to upgrade the precision and performance of the user’s receiver.

The area over which corrections can be made from a single differential facility depends on a number of factors, including timeliness of correction dissemination, range of the correction transmission, area and uniformity of the system’s grid, and user equipment implementations. A differential facility can serve an area with a radius of several hundred miles, depending on the system used and the method of implementation.

Recent innovations in carrier phase tracking differential GPS positioning systems have undergone considerable development and manufacturers are now providing DGPS receivers with carrier phase tracking capabilities. These systems are currently being used for obtaining centimeter accuracies with post processing of data by the U.S. Army Corps of Engineers and others. Similar systems are under development to provide real-time carrier phase tracking on dynamic platforms and will include on-the-fly initialization capabilities in the near future.

3.2.11.1 Maritime Differential GPS

The USCG plans to provide DGPS service for the harbor and harbor approach phase of maritime navigation. Maritime DGPS will use fixed GPS reference stations which will broadcast pseudo-range corrections using maritime radiobeacons. The USCG DGPS system will provide radionavigation accuracy better than 10 meters (2 drms) for U.S harbor and harbor approach areas by 1996, free of charge to the user. Prototype USCG DGPS sites are achieving accuracies on the order of 1 meter. Until the DGPS service is declared operational by the USCG, users are cautioned that signal availability and accuracy are subject to change due to the dependence on GPS, testing of this developing service, and the uncertain reliability of prototype equipment.

Recommended standards for maritime DGPS corrections have been developed by the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104. The USCG is represented on this subcommittee and is using the SC-104 standard for its DGPS system. There are DGPS reference stations available in the market today which are compatible with RTCM Special Committee 104 standard.

The operating plan for maritime DGPS is shown in Figure 3-9.

3.2.11.2 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS is a safety-critical system consisting of the equipment and software which augments GPS. The WAAS provides a signal in space to WAAS users to support en route through precision approach navigation. The WAAS users include all certified aircraft using the WAAS for any approved phase of flight. The signal in space provides three services: (1) integrity data on GPS and Geostationary Earth Orbit (GEO) satellites, (2) differential corrections of GPS and GE0 satellites, and (3) a ranging capability.

The GPS satellite data is received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). This data is forwarded to processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GE0 satellite parameters. This information is sent to a Ground Earth Station (GES) and uplinked along with the GE0 navigation message to the GE0 satellites. The GE0 satellites downlink this data on the GPS Ll frequency with a modulation similar to that used by GPS.

In addition to providing GPS integrity, the WAAS verifies its own integrity and takes any necessary action to ensure that the system meets performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA maintenance personnel.

The FAA is conducting a major system acquisition consisting of the WAAS operational system and functional verification system. The program strategy is to quickly field an initial WAAS consisting of the basic requirements, and to enhance the system to meet the full WAAS requirements through a series of contract options. Implementation of the end-state WAAS will be accomplished in an evolutionary fashion over an estimated six-year period. The initial WAAS will include an initial operational system and a functional verification system. It will be upgraded through a series of pre-planned product improvements to eventually meet all the performance requirements of the WAAS end-state system.

A WAAS initial operational capability is expected in 1997 at which time users will be permitted to navigate with the system. Full operational capability is expected in 2001, at which time WAAS receivers will be certified for primary means of navigation. WAAS Category I precision approaches are anticipated to be introduced beginning in 1997, with as many as 8000 precision approaches expected to be available by 2001. The WAAS operating plan is shown in Figure 3-9.

Substantial benefits will accrue to both users and providers as the WAAS becomes operational and the aviation community transitions to WAAS avionics. Near-term user benefits will result from the use of a single navigation receiver that provides area navigation for all phases of flight and a ten-fold increase in runways approved for precision approaches. When combined with necessary improvements in air traffic control automation, additional user benefits are expected to be derived from reduced IFR separations and more efficient routings. Near-term provider benefits will be derived from the decommissioning of redundant navigation systems and more cost-effective instrument approaches. The WAAS is also expected to be used extensively for numerous other civil applications where improved accuracy, integrity and availability are needed.

3.2.12 Vessel Traffic Services (VTS)

Title 14 U.S.C. requires the USCG to safeguard the nation's ports, waterways, port facilities, vessels, persons, and property in the vicinity of the port from accidental or intentional destruction, damage, loss, or injury. These requirements are addressed by the USCG's Port Safety and Security Program, Marine Environmental Protection Program, and Waterways Management Program. In the course of administering these programs, the USCG assumes responsibility for vessel traffic management and navigation safety regulations. In responding to these requirements, and in furtherance of the National Transportation Plan, the USCG operates Vessel Traffic Services to provide active vessel traffic management in eight selected ports and waterways (see Figure 3-10).

The mission of VTS is to facilitate the safe and efficient movement of vessel traffic to prevent collisions, rammings, groundings, and the loss of lives, property and environmental quality associated with these accidents. Vessel Traffic Services, by

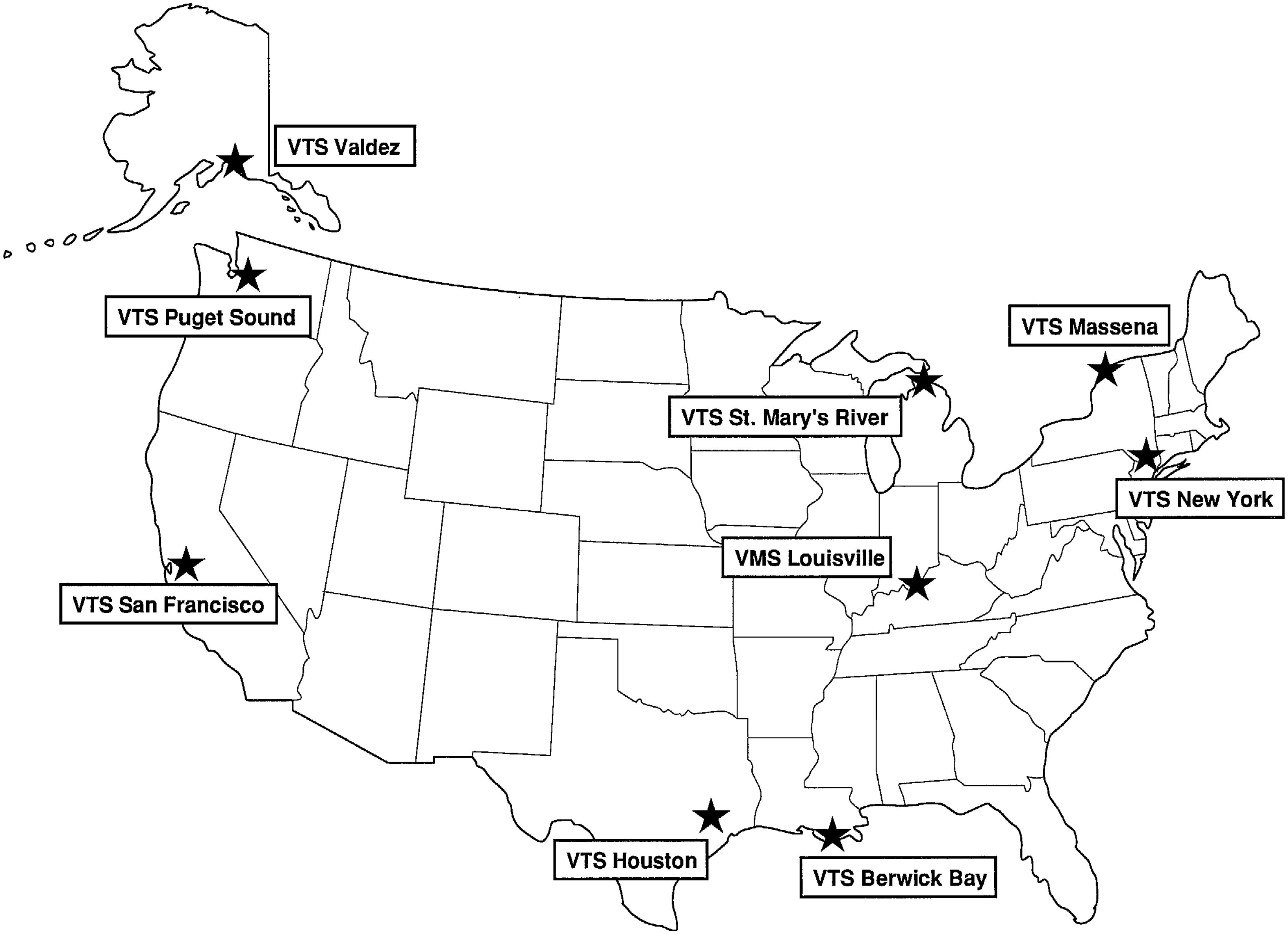


Figure 3-10. Vessel Traffic Service (VTS) Locations

their command and control facilities, also integrate and support other USCG missions including search and rescue, maritime law enforcement, anchorage administration, aids to navigation, port safety and security and national defense.

The SLSDC, created by Public Law 83-358 in 1954 (68 Stat. 93, 33 U.S.C. 981), is responsible for the development, operations and maintenance of the portion of the Saint Lawrence Seaway between Montreal, Quebec, and Lake Erie and within the territorial limits of the United States. In close coordination with the Canadian counterpart, the SLSDC maintains and operates a vessel traffic control center in Massena, New York (see Figure 3-10).

A. Operating Plan

Vessel traffic management can be either passive or active. Passive management involves compliance with the Rules of the Road and other rules and regulations. Active traffic management requires interaction and transfer of information between a shore station and a vessel. The USCG's objective in both passive and active vessel traffic management is to create a disciplined structure of order and predictability.

The USCG's authority, derived from the Ports and Waterways Safety Act (PWSA), allows for varying levels of vessel traffic management. The level of active management to be exercised is determined on a case by case basis and is directed at a specific vessel in a specific situation.

It is a generally accepted principle that VTS functions primarily as an advisory service to coordinate vessel movements through the collection, verification, organization, and dissemination of information. There are times, however, when the maintenance of good order on a waterway requires a VTS to be more directive in its dealings with a vessel. In the exercise of its authority, a VTS can be viewed as three-tiered relative to the level of direction it will exercise:

1. Informational/advisory - the most common use. The great majority of VTS operations are advisory or informative. The vessel operator receives information, determines if action is necessary, and makes adjustments in time to reduce the risks.

2. Recommendations - used occasionally. The VTS determines that action is necessary, and the vessel operator determines what specific action is required to comply, i.e., slow, change course, stop, etc.

3. Specific directions or orders - used in an emergency situation. The most common use of this authority is a VTS directing a vessel not underway to remain at berth or at anchor until an unsafe condition abates. In these cases, the VTS determines necessary and specific action to avoid a potentially dangerous situation.

"Positive Control," as distinguished from the above examples, is any order directed at a vessel by a VTS that affects the vessel's course or speed through the issuance of specific helm or engine commands. This level of involvement is inconsistent with the currently accepted practice within VTS, which is to manage the waterway through varying degrees of VTS interaction, and not by attempting to navigate a vessel from the shore. VTS maintains an informative and advisory role by providing mariners with as much information as is available to assist them in making sound judgements. VTS is active waterways management, not active vessel control. However, the PWSA provides the authority for the USCG to exercise positive control when deemed necessary. Although modem VTSs have the capability to exercise their authority to actively direct a vessel's movement, the USCG policy regarding VTS operations is that ultimate responsibility for safe navigation always remains with the master.

B. User Community

Mandatory participation by vessels is necessary for a successful VTS. Mandatory participation in the USCG's VTS program is generally aimed at vessels that are required to comply with the Bridge-To-Bridge Radiotelephone Act. In general terms, these are:

- Each vessel 20 meters or more in length.
- Each towing vessel 8 meters or more in length while towing.
- Each vessel of 100 or more gross tons carrying passengers for hire.
- Dredges and floating plants engaged in or near a channel or fan-way.
- Vessels certificated to carry 50 or more passengers for hire, while engaged in trade.

Vessels that are specifically required to participate will be identified in VTS regulations and user's manuals.

In addition to participation requirements, vessel operators must be aware of the radiotelephone frequencies and assigned call signs for each VTS. Table 3-5 shows each VTS and its sectors, assigned frequencies, and voice call sign.

C. Acceptance and Use

VTS, as an international philosophy, continues to gain wide acceptance. Although VTS in some nations still tends to focus on economic issues, the trend is now toward safety of vessels, lives, and protection of the environment. Environmental issues are more in the forefront and initiatives are underway to ascertain how VTS can help protect the marine environment, while at the same time supporting a productive maritime economy.

As VTS becomes better known, and its international acceptance grows, the user community also grows. Table 3-6 shows the number of vessels that transited seven

Table 3-5. Vessel Traffic Services Designated' Radiotelephone Frequencies and Assigned Call Signs

VESSEL TRAFFIC SERVICES*	CARRIER FREQUENCY[3] (CHANNEL DESIGNATION)	CALL SIGN
NEW YORK	156.550 MHz (Ch.11) 156.600 MHz (Ch.12) 156.700 MHz (Ch.14)	NEW YORK TRAFFIC
LOUISVILLE	156.650 MHz (Ch.13)	LOUISVILLE TRAFFIC
HOUSTON	156.550 MHz (Ch.11) 156.600 MHz (Ch.12)	HOUSTON TRAFFIC
SARNIA		
MASSENA[4]	156.600 MHz (Ch.12) 156.650 MHz (Ch. 13)	SEAWAY EISENHOWER SEAWAY CLAYTON
BERWICK BAY	156.550 MHz (Ch.11)	BERWICK TRAFFIC
ST. MARY'S RIVER	156.600 MHz (Ch.12)	SO0 CONTROL
SAN FRANCISCO	156.600 MHz (Ch.12) 156.700 MHz (Ch.14)	SAN FRANCISCO TRAFFIC
PUGET SOUND[5]		
Seattle Sector	156.250 MHz (Ch.5A) 156.700 MHz (Ch.14)	SEATTLE TRAFFIC
Tofino Sector	156.725 MHz (Ch.74)	TOFINO TRAFFIC
Vancouver Sector	156.550 MHz (Ch.11)	VANCOUVER TRAFFIC
PRINCE WILLIAM SOUND	156.650 MHz (Ch. 13)	VALDEZ TRAFFIC

Notes

1 The bridge-to-bridge navigational frequency, 156 65 MHz (Channel 13), is used in those vessel traffic service areas where the level of radiotelephone transmissions does not warrant the impact of requiring a designated vessel traffic service frequency The U S USCG will continue to monitor vessel traffic servrce 's use of this frequency and will petition the Federal Communications Commission for designated VTS frequencies if the need should arise

2 Vessel traffic service geographical areas, sectors, and operating procedures are denoted in 33 CFR 161

3 In the event of a communication failure on a designated frequency, either by the vessel traffic center or the vessel, communications may be established on an alternate VTS frequency, or 156 650 MHz (Channel 13): however, only to the extent that doing so provides a level of safety beyond that provided by other means

4 The Canadian St. Lawrence Seaway Authority operates Seaway Beauharnois, Seaway Iroquois, and Seaway Welland for the Canadian sectors of the Seaway

5 A Cooperative Vessel Traffic Service established by the United States and Canada within adjoining waters The appropriate vessel traffic center asministers the rules issued by both nations, however, it will enforce only its own set of rules within its jurisdiction

of the eight USCG VTSs from January 1992 through December 1993. Statistics for the Vessel Traffic Management System in Louisville are not included in this list because this service is only temporarily activated during certain stages of high water.

D. Outlook

In August 1991, the USCG completed a VTS Port Needs Study to provide an economic framework for VTS capital investment decisions into the next century. This project examined 23 potential sites for VTSs and determined the benefit to be gained by establishing a VTS in terms of losses and damages avoided. The USCG is using the results of this study to establish new VTS systems nationwide.

Several initiatives are underway to upgrade and improve equipment at existing Vessel Traffic Centers. New surveillance techniques and equipment as well as enhanced displays are areas the USCG is emphasizing to improve service to the public.

In addition, the SLSDC has been investigating the use of GPS and DGPS in the St. Lawrence Seaway.

3.3 Interoperability of Radionavigation Systems

Radionavigation systems are sometimes used in combination with each other or with other systems. These combined systems are often implemented so that a major attribute of one system will supplement a weakness of another. For example, a system having high accuracy and a low fix rate might be combined with a system with a lower accuracy and higher fix rate. The combined system would demonstrate characteristics of a system with both high accuracy and a high fix rate.

3.3.7 Integrated Navigation Receivers

Integrated navigation receivers combine the signals from multiple sensors to determine position and, often, velocity. Typical sensors include one or more radionavigation receivers and, possibly, compasses and speed sensors. Commercial receivers which combine Transit and Omega or Transit and Loran-C have been widely produced. More recently, receivers have been developed combining GPS with other radionavigation systems to improve availability and coverage, increase integrity, and provide redundancy. Such receivers offer improved performance over the independent use of a single radionavigation system. These receivers fall under the category of augmented GPS.

The FAA has a project to determine the technical feasibility of using both GPS and GLONASS signals in the same user equipment to determine position and be used for navigation. In addition, the RTCA is developing a hybrid GPS/Loran-C MOPS. Integrity information from GPS and another system would provide better availability than when using either system separately - a benefit especially valuable in aviation.

Table 3-6. Vessel Traffic Services Currently Operating

FACILITIES	TOTAL VESSEL TRANSITS		
	1992	1993	1992+1993
NEW YORK, NY	177,789	162,893	340,682
PRINCE WILLIAM SOUND, AK	2,217	2,400	4,617
HOUSTON/GALVESTON, TX	176,277	179,912	356,189
PUGET SOUND, WA	258,666	272,392	53 · ,058
SAN FRANCISCO, CA	90,289	87,419	177,708
BERWICK BAY, LA	88,739	103,897	192,636
ST. MARY'S RIVER, MI	49,769	33,750	83,519
TOTALS	843,746	842,663	1,686,409
AVERAGE			70,267/month

3.3.2 *Interoperable Radionavigation Systems*

Even better performance might be obtained by a user if the time references of different radionavigation systems were related to one another in a known manner. The systems would then be said to be interoperable, and user equipment could more advantageously combine the lines of position from the different systems.

Section 310 of Public Law 100-223, The Airport and Airway Safety and Capacity Expansion Act of 1987, caused an examination of the benefits of coordinating the time references of the GPS and Loran-C systems. While current national security considerations preclude the direct synchronization of Loran-C transmissions to GPS precise time, the USCG has significantly improved the synchronization of Loran-C master stations to UTC. Since GPS is also synchronized to UTC, this provides a de facto synchronization of Loran-C to GPS which might benefit the user.

The continuation of Loran-C overseas offers an opportunity to evaluate the potential of enhancing the use of Loran-C through Time of Transmission (TOT) control techniques. The new chains being planned for Northern Europe are being developed with this technique vice the USCG method of System Area Monitor (SAM) control. Once this system has been installed, and assuming the time base could be related to an independent radionavigation system, i.e., GPS, it is conceivable that appropriately developed user equipment could take advantage of Loran-C stations as ground based pseudolites. In addition to the common time base synchronization control technique, Europe is also considering the benefits of using the Loran-C signal as a method of disseminating GPS integrity messages and differential GPS. This could be accomplished through methods already used in the Loran-C system as it was developed to meet U.S. DOD requirements in the late 1960s and 1970s. In this system, referred to as Clarinet Pilgrim, the Loran-C signal was used as a carrier for passing data to submarines. Applying this concept to pass GPS integrity data and DGPS information might be possible. It remains to be seen if users, as well as commercial receiver manufacturers, will respond favorably to these enhancements.

3.4 Spectrum Certification of Radionavigation Systems

Radionavigation systems require certification of spectrum support prior to their implementation. A key requirement in the certification process is electromagnetic compatibility. Compatibility of systems is a shared responsibility of the DOD and DOT with further delegation of responsibility to the FAA, USCG and DOD frequency management authorities. To assist in meeting these responsibilities, the National Telecommunications and Information Administration (NTIA), in conjunction with the Interdepartment Radio Advisory Committee (IRAC), has developed procedures for the review of radionavigation systems and subsystems by the Spectrum Planning Subcommittee (IRAC/SPS) and for satellite systems review by the Space Systems Group (IRAC/SSG). Full participation of the FCC in these procedures, for operations in spectrum of mutual use by Government and non-government entities, occurs through the FCC liaison representation on the IRAC and its subcommittees. After coordination with the Deputy Associate Administrator, Office of Spectrum Management, the IRAC/SSG initiates the advance publication, international coordination and notification of Government space systems (including those in the radionavigation-satellite service) under the provisions of Articles 8,11,13 and 14 of the International Telecommunication Union (ITU) Radio Regulations and of Chapter 10 of the NTIA Manual. The IRAC/SSG is also responsible for reviewing and responding to the data furnished by other Administrations and the ITU regarding proposed space telecommunications systems in accordance with these ITU articles.

4

Radionavigation System Research, Engineering and Development Summary

4.1 Overview

This section describes Federal Government research, engineering and development activities relating to the Federally provided radionavigation systems and their worldwide use by the U.S. Armed Forces and the civilian community. It is organized in two segments: (1) civil R,E&D efforts to be conducted mainly by DOT and to a lesser extent by NASA and NOAA, and (2) DOD research and engineering (R&E) for military uses.

The DOT R,E&D activities consist of parallel efforts to develop current and future navigation systems to improve existing operations or to identify systems which can replace or supplement those now being used in civil air, land or marine applications. The parallel efforts are described in two major sections, one covering GPS and the other covering all other existing systems (such as VOR, Omega, and Loran-C) now in use or being considered by DOT to meet new or emerging navigation requirements.

Although the DOT R,E&D activities for GPS will proceed in much the same manner as those for other systems, GPS has been identified separately because of its broad multimodal civil and military applications and the consequent need for close cooperation between Federal agencies in its evaluation. Such a cooperative effort will minimize duplication of effort and promote maximum productivity from the limited resources available for civil research. DOT's participation in the evaluation and development of GPS ensures that benefits can be derived from DOD's advances in systems technology.

From the point of view of DOT, the analysis of performance requirements of civil navigation systems involves a variety of complex factors before it can be concluded that a specific system satisfies the principal objective to ensure safety and economy of transportation. These factors involve an evaluation of the overall performance and economics of the system in relation to technical and operational considerations, including vehicle size and maneuverability, vehicle traffic patterns, user skills and workload, the processing and display of navigation information, and environmental restrictions (e.g., terrain hazards and other obstructions). For this reason, a DOT comparison of one navigation system to another requires more than just a simple evaluation of accuracy and equipment performance characteristics. As a first step in the comparison of system capabilities, ten parameters, discussed in Appendix A, can be identified and are listed below:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

User equipment costs are a major consideration if universal civil participation is to be achieved. DOT R,E&D activities may involve evaluations and simulations of low-cost receiver designs, evaluation of future technologies, and determination of future requirements for the certification of equipment.

In contrast to DOT, the DOD R&E activities mainly address evaluations by Armed Forces user groups which are identified by military mission requirements and national security considerations. For this reason, DOD R&E is defined to include all activities before the final acquisition of a navigation system in accordance with detailed system specifications. The DOD view of Transit, Loran-C, TACAN, VOR, ILS, and Omega is that these systems are already developed and, therefore, do not require R&E.

Although there are some similarities between the DOD and DOT analyses of the system parameters, DOD military missions place much greater emphasis on security and anti-jam capabilities. Such factors as anti-jam capabilities, updating of inertial navigation systems, input sensors for weapon delivery, portability, and reliable operation under extreme environmental or combat conditions become very important in establishing the costs of the navigation equipment.

Concurrent with the Federal R,E&D programs, the major cost issues will be evaluated. These evaluations and R,E&D programs will be used to support joint positions related to system mix, phase-in and phase-out, and transition strategies for common-use systems.

The relationship between DOT and DOD R,E&D programs is based on a continuing interchange of operational and technical information on radionavigation systems. DOD R,E&D will be coordinated with DOT R,E&D under the following guidelines:

- DOT will evaluate the costs of all radionavigation systems which meet identified civil user requirements.
- DOT will provide DOD with the most current information on civil user requirements which may have a significant impact on DOD-operated radionavigation systems.
- Consistent with existing DOD policy, DOD will provide information to DOT on GPS receiver designs that may be applicable to civil receiver development.
- DOT will conduct studies of GPS performance capabilities of receivers in order to provide an assessment of their applicability to the civil sector.
- DOD/DOT will not constrain the use of SPS-based differential GPS service as long as applicable U.S. statutes and international agreements are adhered to.
- DOT will cooperate in the development of differential correction reference stations for the best possible differential/integrity network.
- DOT has investigated and is continuing to investigate the use of both GPS and GLONASS signals by the same receiver.

The specific civil R,E&D activities are outlined below in two segments: 1) GPS R,E&D, and 2) R,E&D for other navigation systems including VOR, TACAN, DME, Omega, Loran-C, ILS, and MLS. These activities have been coordinated to achieve efficient use of the limited funds available for R,E&D and to avoid duplication of effort. R,E&D tasks for the individual DOT agencies (FAA, USCG, MARAD, etc.) and related tasks by NASA are addressed and schedules have been specified so that the results of the efforts will be of maximum usefulness to all participants in the program. R,E&D schedules and activities for the FAA, the USCG, and RSPA have been identified respectively under civil aviation, land and marine activities in this document.

4.2 DOT GPS R,E&D

DOT R,E&D activities for GPS have been conducted primarily by the USCG, the FAA, the FHWA, and RSPA. Efforts initially were directed primarily toward determining the capability of GPS to meet civil user needs in the air, land and marine transportation communities. Subsequently, as it became apparent that the GPS capability to be provided to the civil community would not meet all user requirements, efforts have focused on ways of enhancing the system to meet these civil needs. The major DOT air, land and marine R,E&D activities for GPS are described as follows:

A. DOT, with DOD and NOAA as co-sponsors, tasked the Institute for Telecommunications Sciences, with support from the U.S. Army Corps of Engineers (ACOE) Topographic Engineering Center and the DOT Volpe Center, to evaluate the capabilities of augmented GPS technologies for meeting the requirements of aviation, land and marine users. As part of this task, the current requirements of these users were examined, and the augmented GPS options were evaluated to determine if they can satisfy user requirements. The study developed recommendations for an integrated GPS system or systems to meet the needs and requirements of Federal Government users. These recommendations are currently under evaluation.

B. USCG activities focus on verifying and improving the performance of GPS for maritime navigation. There is particular emphasis upon the harbor/harbor approach phase of marine navigation, where augmentation of visual piloting and positioning of other aids to navigation using radio aids to navigation is needed. Major efforts are to:

- Verify the differential GPS concept and techniques developed by the RTCM/SC-104 on differential GPS.
- Initiate action to publish a standard for a marine differential GPS system after the RTCM/SC-104 concepts and techniques have been verified.

C. The FAA's basic R,E&D activities for the introduction of GPS into the NAS are currently focused on the GPS WAAS to satisfy accuracy, coverage, reliability, and integrity for all phases of flight down to Category I precision approach. Additional R,E&D activities to exploit the full capabilities of GPS for civil aviation are continuing.

D. RSPA will continue to review the results of work in the design of low-cost GPS receivers and field tests of GPS performance conducted by other organizations.

E. The ITS field operational test ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) in Chicago has plans to use and test DGPS technology for its in-vehicle route guidance and navigation system.

4.2.1 Civil Aviation

The FAA, through its GPS R,E&D program, is developing the requirements for use of GPS in the national airspace to meet RNP. This includes refining the appropriate standards for GPS airborne receivers and developing the air traffic control methodology for handling GPS area navigation aircraft operation in an environment with non-GPS equipped aircraft. The FAA has certified GPS as a supplemental means of navigation. The use of GPS as a primary means of navigation depends on the successful development, deployment, and operation of the WAAS, as well as the development of appropriate standards, operating procedures, and avionics. The objective of the FAA is to support the integration of GPS and DGPS into the NAS in an evolutionary manner. The evolving WAAS will be a key component of the NAS precision approach and landing architecture. The WAAS is projected to meet all requirements for Category I precision approach. Additional augmentation will be required to support Category II and III operations. Other augmentation and auxiliary/hybrid sensors may also be employed, and are currently being examined. There is close cooperation between FAA, DOD, and industry in these efforts. A Memorandum of Agreement between FAA and DOD to implement GPS for civil aviation was signed on May 15, 1992.

The FAA is actively supporting the activities of the ICAO and RTCA, Inc. in the definition of the Global Navigation Satellite System (GNSS) and associated implementation planning guidelines. The GNSS is intended to be a worldwide position, velocity and time determination system. GNSS will include one or more satellite constellations, end-user receiver equipment, a system integrity monitoring function, and ground-based services augmented as necessary to support the RNP for specific phases of flight. GPS will be the primary satellite constellation used for navigation during early GNSS implementation. The FAA’s activities in support of ICAO and RTCA will ensure that satellite navigation capabilities are implemented in a timely and evolutionary manner on a global basis.

The FAA has examined a variety of implementation strategies for incorporating GPS-based navigation into the NAS. Consequently, the FAA is implementing satellite navigation through an industry/government partnership that achieves user benefits in all phases of aviation operations.

The FAA is actively pursuing technology related to GPS augmentation in order to achieve a new primary means of navigation capability. While several methods are being analyzed and developed, WAAS is fully endorsed and is being developed by the FAA. This satellite-based augmentation concept has been operationally demonstrated for use in all phases of flight with a system prototype. Production of the system is scheduled for commissioning in 1997.

A. FAA Research, Engineering and Development Accomplishments To Date

- The FAA has allowed the use of GPS positioning data as input to multi-sensor navigation systems for selected IFR phases of flight using existing criteria for operating minima, flight inspection, obstacle clearance, and ATC separation standards.

- The FAA has approved the use of GPS as a supplemental civil aviation navigation system and as a primary system for oceanic and specified remote areas.

- The FAA has published a GPS National Aviation Standard.

- The FAA participated in the development of a Minimum Aviation System Performance Standard (MASPS) for GPS Special Use Category I precision approaches and has published an Order describing its use on private grounds.

- The FAA has initiated an “overlay” project to quickly certify about 5,000 GPS nonprecision approaches.

- The FAA has supported the satellite navigation activities of the Air Transport Association, the National Business Aircraft Association, and the Aircraft Owners and Pilots Association user groups to develop customer capabilities.

- The FAA has developed a U.S./GPS and Commonwealth of Independent States (C.I.S.)/GLONASS common receiver test set to collect data and support developing avionics MOPS.

- The FAA has established cooperative research agreements with aviation community organizations such as NASA Ames, Ohio University, Stanford University, Honeywell, and Alaska Airlines to investigate the use of GPS for precision approaches

- The FAA has established international cooperation for developing the GNSS through the ICAO Future Air Navigation System (FANS) IV research and development working group.

- The FAA has participated in the development of the WAAS MOPS.

B. Planned FAA Research, Engineering and Development GPS Activities

For primary means of navigation, the FAA is pursuing the development of the WAAS to enhance the availability and integrity of GPS. IOC is scheduled for 1997. The FAA is also researching the development, deployment, and certification of the WAAS as a public-use system for Category I precision approaches. There is a continuing certification standards R,E&D effort to support Category I.

Emphasis is placed on the GPS-based navigational benefits and associated activities for the oceanic, domestic en route, nonprecision approach, and Category I precision approach phases of flight. This reflects that these benefits are near-term, while the capability of GPS to provide navigation guidance for Category II and III precision approaches and airfield surface navigation remains relatively long-term and requires further research.

Activities are ongoing to study the potential impact of radio frequency interference (RFI) and jamming and spoofing on navigation and landing operations and to develop suitable mitigation techniques for the avionics, ground-based receivers, and overall augmentation systems as appropriate. Initial focus is on phases of flight down to CAT I, and will be expanded to include CAT II/III precision approach performance standards.

Long-term R,E&D is being conducted to determine the feasibility of augmenting GPS for conducting Category II and III precision approaches. This activity includes multiple FAA funded demonstrations by a number of contractors, as well as (potentially) non-government funded demonstrations and studies by industry and academia worldwide.

Other activities are to:

- Develop RNP parameters for all phases of flight from oceanic en route to CAT III precision approach, and surface navigation. Early outputs from this task are needed to support rule-making for CAT I operations as well as en route operations based on GPS augmented with WAAS. RNP for CAT II/III are deferred somewhat but are required by mid to late 1995 to support decision-making regarding the far-term NAS precision approach and landing (NASPALS) architecture.

- Develop CAT II/III standards. This activity contains multiple elements such as development of TSOs, FAA Orders and ACs, and configuration management updates of NAS documentation.

- Track the RF carrier phase during high dynamic movements to obtain sub-meter navigation accuracies.

- Obtain real-time (1 second or less) integrity.

- Provide continuity of service which can meet requirements for landing and rollout under very low visibility weather conditions.

Table 4-l shows the FAA schedule for the development of GPS performance standards for civil avionics.

4.2.2 Civil Marine

The R,E&D activities of the USCG related to marine uses of GPS have historically been: (1) user field tests for comparative assessment of GPS versus alternative aids to navigation; (2) assessment of SPS performance potential; and (3) assessment of using differential GPS for various applications including harbor/harbor approach

Table 4-1. Development of GPS Performance Standards for Civil Avionics

PHASE OF FLIGHT	CALENDER YEARS								
	1992	1993	1994	1995	1996	1997	1998	1999	2000
GPS AS INPUT TO MULTI-SENSOR NAV.									
EN ROUTE OCEANIC	COMPLETE								
EN ROUTE DOMESTIC	COMPLETE								
TERMINAL	COMPLETE								
NONPRECISION APPROACH	COMPLETE								
GPS - SUPPLEMENTAL NAV.									
EN ROUTE OCEANIC		COMPLETE							
EN ROUTE DOMESTIC		COMPLETE							
TERMINAL		COMPLETE							
NONPRECISION		COMPLETE							
GPS AUGMENTED FOR RNP									
EN ROUTE OCEANIC (FMS/IRS/ADC)									
EN ROUTE OCEANIC									
EN ROUTE DOMESTIC									
TERMINAL									
NONPRECISION APPROACH									
PRECISION APPROACH CAT I									
PRECISION APPROACH CAT II & III (DETERMINE FEASIBILITY)									

navigation. The purpose of the marine program is to acquire a sufficient base of knowledge to determine those missions of the marine fleet for which the GPS system can satisfy the navigation performance requirements. Issues important to the use of GPS for marine navigation include:

- Accuracy: Non-augmented GPS cannot provide the accuracies needed by marine users in some applications, including commercial fishing, where repeatable accuracies of 50 meters using Loran-C are commonplace; the offshore industry, which requires 1 meter accuracy; harbor/harbor approach, which requires 8-20 meter accuracy; and inland waterway navigation, the requirements of which are undefined, but will surely be more restrictive than that of harbor navigation.

- Technical and Economic Factors: Technology, and a rapidly-developing satellite constellation, have driven the costs of GPS equipment dramatically lower than that predicted two years ago. This trend should also occur over the next two years with DGPS receivers. Government activity in this area will be limited to participation with industry in the development of performance standards and functional requirements for receivers to support carriage requirements for vessels.

- Use with ECDIS: DGPS receivers are most effective when used with some form of automated chart display. Its extreme accuracy (small fractions of a minute of latitude and longitude) is difficult to plot manually, and its capability of outputting position data at intervals of one second or less is far beyond the human ability to plot the information in real time. Research into the integration of highly accurate position sensors such as DGPS is ongoing.

The USCG has completed its proof-of-concept for DGPS use in harbor/harbor approach navigation. The system greatly exceeded the required levels of performance. Future work will focus on jamming and spoofing of the GPS signal. The USCG is working with the RTCM to develop correction messages for geostationary satellites that will provide ranging signals. Working with the RTCM, the USCG has participated in developing a message to broadcast ionospheric measurements which will be thoroughly characterized through field testing. This message, the Type 15, will extend the high accuracy achieved in the vicinity of the reference station out to several hundred miles.

4.2.3 Civil land

Land radionavigation users, unlike air and marine users, do not come under the legislative jurisdiction of any agency. For this reason, RSPA has attempted to monitor land user activities and identify R,E&D activities applicable to user needs. Limited RSPA R,E&D performed in past years through the Volpe Center indicated some limitations to the serviceability of GPS to land users in certain urban areas. RSPA will monitor technology developments in the private sector and the results of other government sponsored R,E&D activity in the following areas:

- Land user equipment availability and cost.
- GPS land performance.
- Differential GPS technology development and system performance.
- Land navigation and radiolocation applications.
- Commercial system development status, performance and applications.
- Possible Government use of commercial navigation, radiolocation, and communications systems for air, land and marine users.

RSPA, FHWA, and NHTSA will also participate in joint industry, user, and government groups developing standards for using radionavigation equipment displays and databases in land vehicles. RSPA, as the DOT focal point for hazardous materials transportation, will also study GPS tracking technologies.

Several departments and agencies of the Federal Government are sponsoring R,E&D activities that use existing radionavigation systems for various land uses. Federal and state governments and private industry are conducting research, as part of the ITS program, to assess the feasibility of using in-vehicle highway navigation and automatic vehicle location to satisfy the needs of ITS user services. Table 4-2 lists operational tests using GPS that are wholly or partially funded by FHWA. These operational tests are also shown in Figure 4-l. A complete listing of R&D studies and operational tests wholly or partially funded by FHWA, FTA and NHTSA can be found in DOT’s *Intelligent Vehicle Highway Systems Projects, March 1994.* These tests are focused on the development of ITS user services that will achieve improvements in safety, mobility, and productivity, and reduce harmful environmental impacts, particularly those caused by traffic congestion. The following paragraphs describe some of these tests.

ADVANCE is a cooperative effort to evaluate the performance of the first large-scale, dynamic route guidance system in the United States. Participants include the Illinois DOT, Motorola, Inc., the Illinois Universities Transportation Research Consortium, and the FHWA. Up to 5,000 private and commercial vehicles in the northwestern suburbs of Chicago will be equipped with in-vehicle navigation and route guidance systems. Vehicles will serve as probes, providing real-time traffic information. This information will then be transmitted to the equipped vehicles and used to develop a preferred route. The routing information will then be presented to the driver in the form of dynamic routing instructions.

Table 4-2. Examples of ITS Operational Tests Using GPS

FHWA Tests funded prior to FY 93 using GPS

Test Name			
ADVANCE (Chicago)	GPS	Geolocation for map-matching	1994-7
TRAVTEK (Orlando)	GPS	Geolocation for map-matching	1992

FY 93 Operational Tests using GPS

Test Name			
Colorado Advanced Public Transportation	GPS	Automated Vehicle Location for mass transit scheduling	1995
Iowa, Minnesota, Wisconsin Border Crossings	GPS	Mileage determination	1994-5
New York City Mass Transit Authority Travel Information Test	GPS	Automated Vehicle Location for mass transit scheduling	1994-5

FY 94 Operational Tests using GPS

Test Name			
Atlanta En Route Traveler Advisory	DGPS	Geolocation for radio tuning information	1996
Idaho Motor Carrier Safety Assistance Program Out-of-Service Verification	GPS	Automated Vehicle Location	1995-6
Seattle Wide Area Communications System/Bellevue Smart Traveler	GPS	Geolocation for map-matching	1995-6
Project NORTHSTAR, New York/Connecticut/ New Jersey-Metro Area	GPS/DGPS	Geolocation for mayday	1995-6
Advanced Rural Transportation Information and Coordination (Minnesota)	GPS	Geolocation for routing and mayday	1995-6
Colorado Mayday	GPS	Geolocation for mavdav	1995

All dates are by the scheduled time of test.

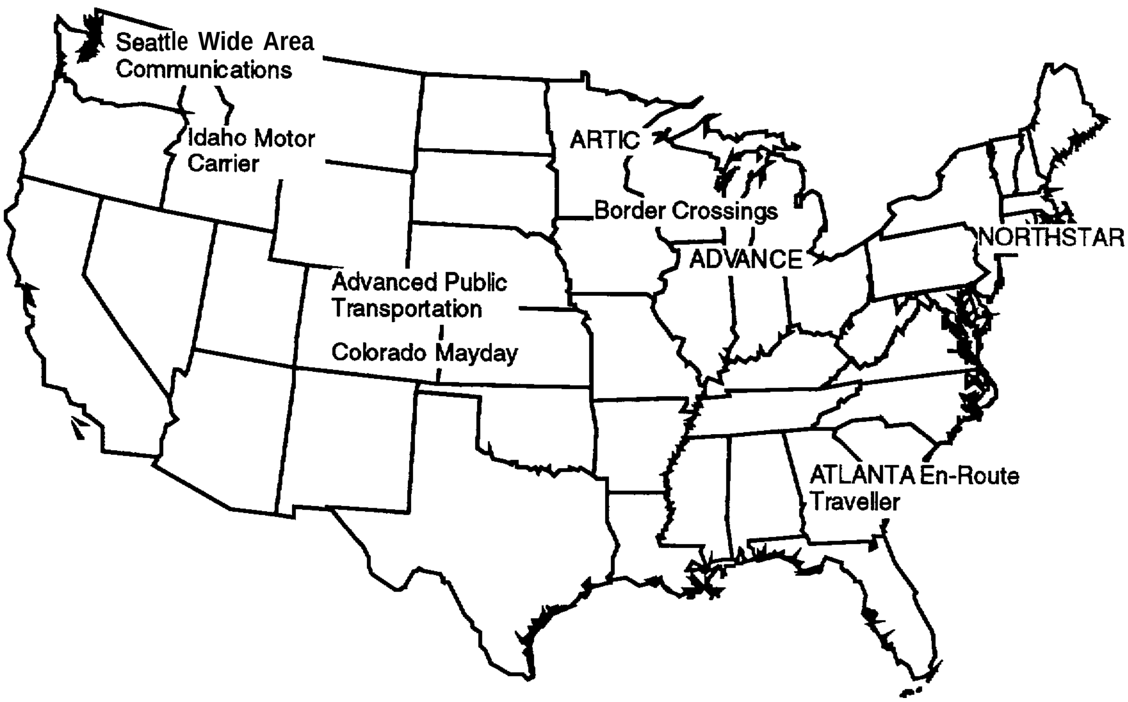


Figure 4-1. Selected ITS Operational Tests Using Radionavigation

The Onboard Automated Mileage Test in Iowa, Minnesota, and Wisconsin is a three state project that will test and evaluate the effectiveness of using GPS and first-generation onboard computers to record the miles driven within a state for fuel tax allocation purposes in a manner acceptable to state auditors. The system will automatically record mileage by specific roadway as well as state border crossings using GPS and vehicle location technology with a map-matching algorithm.

The Baltimore Mass Transit Administration (MTA) is implementing an automatic vehicle location system that will provide bus status information to the public while simultaneously improving bus schedule adherence and labor productivity. A prototype system involving 50 buses is being tested with Loran-C receivers and 800-MHz radios. The buses' location is determined by the receiver and the information is transmitted to central dispatch center. Off-schedule buses are identified so corrective action can be taken. The system will be expanded to include all 900 Baltimore transit buses and GPS inputs will replace Loran-C for vehicle location.

Dallas Area Rapid Transit (DART) has installed an Integrated Radio System that includes automatic vehicle location. When completely installed in mid-1994, 8,323 transit buses, 200 mobility impaired vans and 142 supervisory and support vehicles will be equipped. GPS will generate vehicle location information.

The Colorado Mayday System operational test calls for the installation of in-vehicle devices which are capable of capturing a snapshot of available GPS location data, and other vehicle related emergency information, and a communications system primarily based on cellular telephones and specialized mobile radio units. A control center will be established to receive and process emergency assistance requests from the in-vehicle units and determine vehicle location from the GPS data that was included in the emergency assistance request. The control center will determine the nature of the request and forward it to the appropriate response agency for action. The motorist will then be notified by the control center on the actions taken and the expected response time. The in-vehicle unit will be capable of automatically activating the emergency assistance request under some conditions where the driver may be incapacitated. In addition, there will be a button box that will allow the driver to initiate a specialized call for assistance ranging from vehicle service or repair to medical emergencies. The Denver, Colorado Rapid Transit District (RTD) Passenger Information Display System will use data gathered from the AVL system, currently being installed on all RTD buses, to provide information to video monitors at selected locations regarding estimated bus departures for waiting bus passengers.

A number of services are evolving that use GPS-based AVL systems. In mass transit systems, they are being proposed for use in computer aided dispatch, traffic signal pre-emption and bus stop annunciation. Within the trucking industry, companies have equipped vehicles with GPS receivers to aid in fleet management. Knowing the location of every vehicle across the nation at any instant in time will allow more efficient planning and operations. Urgent pick-up and delivery services to customers will be possible and rapid and optimal rescheduling of each vehicle's itinerary is expected to result in improved productivity.

4.3 DOT R,E&D for Other Navigation Systems

The main purposes of DOT navigation systems R,E&D are to improve reliability and service, decrease costs, and satisfy new requirements. The major DOT R,E&D for systems other than GPS is outlined in the context of air, land and marine areas of operation.

A. Air

The FAA will continue to modernize VOR/DME to reduce operation and maintenance costs and to improve the performance of these aids. The FAA will also continue to monitor the performance of Omega on oceanic air routes and the use of Omega and Loran-C as supplements to VOR/DME.

B. Marine

The DOT marine R,E&D for existing systems is composed of several programs. USCG R,E&D projects focus on system enhancements and techniques for improving navigation safety in the harbor/harbor approach phase of marine navigation, principally involving shipboard displays as well as enhanced VTS equipment designs to prevent vessel casualties, loss of life, or pollution of the marine environment. A project is also under way to evaluate the requirements for harbor/harbor approach navigation system performance.

MARAD, in cooperative research with the private sector and the USCG, has developed a computerized decision support system for safe navigation which combines artificial intelligence technology, digital chart data bases, vessel maneuvering data, and precise positioning information to enhance piloting performance in the harbor/harbor approach and coastal phases of navigation. The system has been undergoing an operational evaluation aboard ship which should prove its contribution to safe navigation.

C. Land

As navigation benefits to land users become more apparent, and as receiver equipment costs decrease due to technology improvements and expanding user markets, adaptation of the existing navigation systems to serve a variety of land users will prove cost-effective. Typical applications include site registration for remote site location, highway records, land management, and resource exploration; AVM/AVL for truck fleets, railroad transportation management, buses, and police and emergency vehicles; driver information systems for highway vehicles; and navigation applications for highways and remote areas.

4.3.1 Civil Aviation

The aviation community has recognized that the existing ground-based navigation systems have reached their full potential. Consequently, the FAA's R,E&D program will concentrate on the exploitation of satellite-based technologies, specifically GPS.

The R,E&D activities of the FAA are broadly directed toward improving navigation systems serving civil and military air users. The activities cover five phases of flight: (1) oceanic and domestic en route; (2) nonprecision approach; (3) remote areas; (4) vertical-flight IFR operations; and (5) precision approach and landing.

The FAA navigation program has three specific goals: (1) to provide information that will support FAA recommendations on the future mix of navigation aids; (2) to assist in the near-term integration of existing navigation aids into the NAS as supplements to VOR/DME; and (3) to provide information that will support the definition of long-term navigation opportunities.

Possibilities exist to develop receiver avionics which combine two radionavigation signals such as GPS/Loran-C, GPS/GLONASS, GPS/Omega, and GPS/VOR/DME, and thereby significantly improve user navigation performance. FAA, in cooperation with industry, is developing standards under which an individual system or combination of systems may be certified to meet RNP in an aircraft conducting IPR, en route, and terminal area operations, including nonprecision approach, in controlled U.S. airspace.

In the long term, communications, navigation, and surveillance (CNS) may be combined into an integrated communications and navigation system (ICNS) providing a seamless system for civil users. Low-altitude users, including VFR as well as IFR traffic, could be accommodated more easily in the NAS since one ICNS system would respond to the needs of all users.

ICNS services would extend ATC service to more airspace in support of flexible routes. This airspace includes extreme (low and high) altitudes, oceanic, offshore, remote, and urban environments.

Time-based navigation and ATC practices in the en route and terminal environment would involve issuing time-based clearances to certain aircraft which can navigate with sufficient precision to fly space-time profiles and arrive at points in space at specified times. Aircraft equipped with advanced flight navigation and management systems may be able to receive clearances directly from ground automation equipment, and follow such clearances automatically along trajectories of their choice, either to maximize fuel efficiency or to minimize time. This will also enhance the utilization efficiency of the NAS, allowing increased capacity without a proportional increase in infrastructure expenditures.

Automatic dependent surveillance (ADS) is defined as a function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a datalink for use by air traffic control. Automatic dependent surveillance R,E&D will develop functions to permit tactical and strategic control of aircraft. Automated position report processing and analysis will result in nearly real-time monitoring of aircraft movement. Automatic flight plan deviation alerts and conflict probes will support reductions in separation minima and increased accommodation of user-preferred routes and trajectories. Graphic display of aircraft movement and automated processing of data messages, flight plans, and weather data will significantly improve the ability of the controller to interpret and respond to all situations without an increase in workload.

Oceanic En Route

Oceanic navigation is achieved through the use of Omega and inertial navigation systems. Limited accuracy and cumulative errors result in a lack of timely, accurate, and reliable aircraft position determination, reporting, and tracking. This forces large, safety-conscious spatial and temporal separation standards for aircraft flying trans-oceanic routes.

Domestic En Route

Domestic en route navigation is achieved through the use of VOR/DME, GPS, Loran-C, NDB, and TACAN. The current primary navigation system for the domestic en route structure relies on navigation between ground-based VORs.

Nonprecision Approach

No initiatives beyond the use of GPS are contemplated for this phase of flight at this time.

Remote Areas (including offshore)

Although VOIUDME coverage meets most civilian user requirements, there are areas, such as some mountainous regions and low-altitude airspace areas, where there is a requirement for air navigation service that VOR/DME does not presently provide. Alternatives being investigated to provide the required coverage include additional VOR/DME facilities, and supplementing the existing VOR/DME system with GPS or Loran-C. Currently, Omega/VLF, GPS, and Loran-C (in specific areas) are approved as a supplement to VOR/DME.

Vertical-Flight IFR Operations

GPS-based navigation offers new opportunities for vertical-flight aircraft to operate more efficiently in the NAS. As prime examples, significant benefits can be derived in the near term through virtually uninterrupted emergency medical services to hospitals and trauma centers in all weather operations, undelayed passenger carrying operations and optimized low-altitude air routes.

Emergency medical services have long recognized the importance of delivering prompt medical attention and expeditiously transporting patients to and between medical facilities. GPS-based navigation enhances this potential by enabling instrument approaches to every hospital with sufficient obstacle-free airspace. The FAA is investigating how best to maximize this new capability through reduced TERPS obstacle clearance areas, steeper glide slopes, and curved approaches for vertical-flight aircraft. The first stage of this testing focuses on nonprecision approaches. Tests of vertical-flight aircraft performance during nonprecision approaches are being conducted at four heliport sites. Data collection will focus on system-use accuracy and pilot workload over various combinations of glide slopes and curved approaches. Follow on testing will examine precision approach and en route navigation requirements. The results gained during these tests can also be applied to a wide variety of other vertical-flight aircraft missions.

Passenger-carrying operations using vertical-flight aircraft is one method of reducing congestion and delays at high activity airports and on highways. In terminal areas, however, this will work most efficiently if vertical-flight aircraft can operate independently of the regular fixed-wing traffic flow. The high accuracy of

GPS-based navigation together with the unique flight capabilities of vertical-flight aircraft can enable undelayed approaches. The FAA is examining methods to optimize these traffic patterns and approaches into high activity airports to eliminate delays regardless of the weather.

The vertical-flight community has identified the need to have low altitude IFR routes that are nearly direct and separate from high traffic fixed-wing routes. Flying IFR at low altitudes is also important in many areas of the United States, most notably the northeast United States, to avoid the frequent icing conditions. Due to the limitations of VOR, only one such IFR route had been feasible. GPS-based navigation can enable these types of routes to be developed wherever a need exists. The FAA has begun analyzing these requirements and the best methods to integrate this route structure into the NAS.

Precision Approach and Landing

Presently, the ILS ground-based system is the only system used to support CAT II/III operations. GPS without proper LADGPS augmentation cannot support CAT II/III operations. The FAA is currently funding research designed to investigate the feasibility and utility of various LAAS augmentations to support CAT II/III operations. Until the research is completed, CAT II/III requirements will be met by ILS. From a strategic planning perspective, several other CAT II/III future architectures are being considered.

Local-area DGPS systems, ILS, GLONASS and other navigation sources and sensors may play roles of varying significance in the far-term precision approach architecture.

4.3.2 Civil Marine

The USCG plans for improving marine navigation systems, which serve the civil maritime user, are described below. They cover the following phases of marine navigation: inland waterway, harbor/harbor approach, coastal, and ocean.

Inland Waterway and Harbor/Harbor Approach

No efforts are being expended by the USCG to develop any radionavigation systems for inland waterways. However, the USCG is anticipating expansion of DGPS through a joint effort with the ACOE to meet navigation requirements of certain inland waterways.

There is no existing Federally provided radionavigation system capable of meeting the 8 to 20 meter (2 drms) accuracy required for marine navigation in harbor/harbor approach areas. Loran-C can meet these requirements in a few selected areas. The USCG developed and demonstrated a differential Loran-C system that nearly met these accuracy requirements in many, but not all, major harbor areas. This effort has been terminated in favor of efforts involving DGPS.

USCG DGPS will be implemented to meet the marine navigation requirements of harbor/harbor approach. The system will use fixed GPS reference stations which will broadcast differential corrections over USCG radiobeacons. The system has potential application in marine and terrestrial navigation and survey operations. The system is based on differential message and data standards developed by a multidisciplinary committee under the sponsorship of the RTCM. A proof of concept differential system, including the radiobeacon data link and user equipment, was tested in 1990. It is being refined in preparation for deployment to the field.

Ship simulator studies were conducted to evaluate the minimum radionavigation sensor accuracy and display requirements for piloting in restricted waterways. These studies helped to provide a basis for establishing requirements for harbor/harbor approach navigation system performance.

Coastal

Loran-C and GPS meet the radionavigation requirements for the coastal phase of marine navigation. As it is implemented, DGPS will also be usable in much of this navigation phase. No R,E&D activities are ongoing or planned.

Oceanic

The primary system used for oceanic navigation is GPS. Omega will also be used by a declining user base until it is phased out. No R,E&D activities are ongoing or planned.

4.3.3 Civil Land

The Baltimore Mass Transit Administration is testing a prototype AVL system using Loran-C receivers. Bus location is determined by the receiver and the information is transmitted to a central dispatch center. Off-schedule buses are identified for corrective action. The system will be expanded to include all 900 Baltimore transit buses and GPS inputs will replace Loran-C for vehicle location.

4.4 GPS R&D Ongoing and Planned by NOAA

NOAA continues to perform GPS research and development for precise geodetic modeling and applications.

NOAA continues to improve the modeling for the determination of precision GPS orbits for precision applications such as precise determination of global tide gauges, precise determination of orthometric heights based on a combination of double-differenced GPS and a gravimetric geoid, and measurement of polar motion of the Earth.

NOAA's GPS geodetic program includes the formation of a geodetic network of Continuously Operated Reference Stations (CORS) whose geodetic positions are known and consistent at the few-centimeter level nationwide. NOAA continues to work closely with the USCG, the FAA, and other agencies to help develop standards for CORS activities, to provide geodetic control to CORS sites and other monuments, and to make arrangements for access to GPS measurements for widespread public use.

NOAA continues its commitment to GPS research and development, improved GPS orbits, and a geometric network which is accessible and precise both in the geometric sense (NAD83) and in the orthometric sense (NAVD88). One of NOAA's primary charters is to encourage all public and private users to reference their positioning and navigation results to the NOAA geodetic networks.

4.5 GPS R,E&D Planned by NASA

NASA is conducting R,E&D in a number if GPS application areas in the space, aeronautics, and terrestrial environments. These efforts include:

- ***Space Applications:*** The emphasis in the space applications R,E&D of GPS is primarily on development of off-the-shelf GPS receivers that can be installed in instrumented spacecraft. These receivers will be capable of providing onboard navigation products, providing GPS time signals for distribution to spacecraft systems and instruments, providing necessary data for post-pass processing in support of science data collection, and determining spacecraft attitude.

  Particular emphasis is being placed on research supporting the determination of attitude using spaceborne GPS receivers. NASA is working with industry to refine attitude determination techniques using GPS for both the Lewis and Clark small satellite program and for the International Space Station.

  NASA is also continuing to refine the post-pass processing techniques used to support precise analysis of scientific data requiring precise knowledge of spacecraft position at data collection time.

- ***Aeronautics Applications:*** GPS receivers aboard NASA aircraft are being used for both aeronautics research and in support of airborne scientific observations. There are numerous projects throughout NASA where GPS technology is being developed for these purposes. For example, in the aeronautics research area, GPS is being used in work being done at the Langley Research Center in wake vortex measurement systems in support of the terminal area productivity enhancement research. NASA is also conducting research using GPS for precise pointing of instruments from the Stratospheric Observatory For Infrared Astronomy (SOFIA) aircraft, use in the Airborne Synthetic Aperture Radar (AIRSAR) program in the production of Digital Elevation Models (DEMs) of the earth's surface, and for positioning of aircraft while taking annual thickness measurements of the Greenland ice sheet.

- ***Terrestrial Applications:*** NASA is sponsoring the continued development of the International GPS Service (IGS) for Geodynamics. Areas of research include continued enhancement of the software used to determine orbit ephemerides and techniques for improving measurement accuracy to the 1 mm level.

Appendix A

System Descriptions

This appendix addresses the characteristics, capabilities, and limitations of existing and proposed common-use radionavigation systems. The systems covered are:

- Loran-C
- Omega
- VOR, VOR/DME, and TACAN
- ILS
- MLS
- Transit
- Aeronautical Radiobeacons
- Maritime Radiobeacons
- GPS
- Augmentations to GPS
- VTS

A.1 System Parameters

All of the systems described are defined in terms of system parameters which determine the use and limitations of the individual navigation system's signal in space. These parameters are:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

A. 7. I Signal Characteristics

Signals-in-space are characterized by power levels, frequencies, signal formats, data rates, and any other information sufficient to completely define the means by which a user derives navigational information.

A. 7.2 Accuracy

In navigation, the accuracy of an estimated or measured position of a craft (vehicle, aircraft, or vessel) at a given time is the degree of conformance of that position with the true position of the craft at that time. Since accuracy is a statistical measure of performance, a statement of the accuracy of a navigation system is meaningless unless it includes a statement of the uncertainty in position which applies.

Statistical Measure of Accuracy

Navigation system errors generally follow a known error distribution. Therefore, the uncertainty in position can be expressed as the probability that the error will not exceed a certain amount. A thorough treatment of errors is complicated by the fact that the total error is comprised of errors caused by instability of the transmitted signal, effects of weather and other physical changes in the propagation medium, errors in the receiving equipment, and errors introduced by the human navigator. In specifying or describing the accuracy of a system, the human errors usually are excluded. Further complications arise because some navigation systems are linear (one-dimensional) while others provide two or three dimensions of position.

When specifying linear accuracy, or when it is necessary to specify requirements in terms of orthogonal axes (e.g., along-track or cross-track), the 95 percent confidence level will be used. Vertical or bearing accuracies will be specified in one-dimensional terms (2 sigma), 95 percent confidence level.

When two-dimensional accuracies are used, the 2 drms (distance root mean squared) uncertainty estimate will be used. Two drms is twice the radial error drms. The radial error is defined as the root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. It is often found by first defining an arbitrarily-oriented set of perpendicular axes, with the origin at the true location point. The variances around each axis are then found, summed, and the square root computed. When the distribution of errors is elliptical, as it often is for stationary, ground-based systems, these axes can be taken for convenience as the major and minor axes of the error ellipse. Then the confidence level depends on the elongation of the error ellipse. As the error ellipse collapses to a line, the confidence level of the 2 drms measurement approaches 95 percent; as the error ellipse becomes circular, the confidence level approaches 98 percent. The GPS 2 drms accuracy will be at 95 percent probability.

DOD specifies horizontal accuracy in terms of Circular Error Probable (CEP-the radius of a circle containing 50 percent of all possible fixes). For the FRP, the conversion of CEP to 2 drms has been accomplished by using 2.5 as the multiplier.

Types of Accuracy

Specifications of radionavigation system accuracy generally refer to one or more of the following definitions:

- Predictable accuracy: The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix B discusses reference systems and the risks inherent in using charts in conjunction with radionavigation systems).

- Repeatable accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

- Relative accuracy: The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

A. 1.3 Availability

The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

A. 1.4 Coverage

The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the navigator to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

A. 1.5 Reliability

The reliability of a navigation system is a function of the frequency with which failures occur within the system. It is the probability that a system will perform its function within defined performance limits for a specified period of time under given operating conditions. Formally, reliability is one minus the probability of system failure.

A. 1.6 Fix Rate

The fix rate is defined as the number of independent position fixes or data points available from the system per unit time.

A. 7.7 Fix Dimensions

This characteristic defines whether the navigation system provides a linear, one-dimensional line-of-position, or a two-or three-dimensional position fix. The ability of the system to derive a fourth dimension (e.g., time) from the navigational signals is also included.

A. 7.8 System Capacity

System capacity is the number of users that a system can accommodate simultaneously.

A. 1.9 Ambiguity

System ambiguity exists when the navigation system identifies two or more possible positions of the vehicle, with the same set of measurements, with no indication of which is the most nearly correct position. The potential for system ambiguities should be identified along with provision for users to identify and resolve them.

A. 1.10 Integrity

Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

A.2 System Descriptions

This section describes the characteristics of those individual radionavigation systems currently in use or under development. These systems are described in terms of the parameters previously defined in Section A. 1. All of the systems used for civil navigation are discussed. The systems which are used exclusively to meet the special applications of DOD are discussed in the CJCS MNP.

A.2.1 Loran-C

Loran-C was developed to provide DOD with a radionavigation capability having longer range and much greater accuracy than its predecessor, Loran-A. It was subsequently selected as the Federally provided radionavigation system for civil marine use in the U.S. coastal areas. For further Loran-C coverage information, consult the Loran-C Users Handbook (available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402).

A. Signal Characteristics

Loran-C is a pulsed, hyperbolic system operating in the 90 to 110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of radio frequency (RF) energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The measurements of time difference (TD) are made by a receiver which achieves high accuracy by comparing a zero crossing of a specified RF cycle within the pulses transmitted by master and secondary stations within a chain. Making this signal comparison early in the ground wave pulse assures that the measurement is made before the arrival of the corresponding sky waves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To aid in preventing sky waves from affecting TD measurements, the phase of the 100 kHz carrier of some of the pulses is changed in a predetermined pattern. Envelope matching of the signals is also possible but cannot provide the advantage of cycle comparison in obtaining the full system accuracy. The characteristics of Loran-C are summarized in Table A- 1.

B. Accuracy

Within the published coverage area, Loran-C will provide the user who employs an adequate receiver with predictable accuracy of 0.25 nm (2 drms) or better. The repeatable accuracy of Loran-C is usually between 18 and 90 meters. Accuracy is dependent upon the Geometric Dilution of Precision (GDOP) factors at the user's location within the coverage area.

Loran-C navigation is predominantly accomplished using the ground wave signal. Sky wave navigation is feasible, but with considerable loss in accuracy. Ground waves and to some degree sky waves may be used for measuring time and time intervals. Loran-C was originally designed to be a hyperbolic navigation system. However, with the advent of the highly stable frequency standards, Loran-C can also be used in the range-range (rho-rho) mode of navigation. This is accomplished by a comparison of the received signal phase to a known time reference to determine propagation time and, therefore, range from the stations. It can be used in situations where the user is within reception range of individual stations, but beyond the hyperbolic coverage area. Because the position solution of GPS provides precise time, the interoperable use of rho-rho Loran-C with GPS appears to have merit.

The inherent accuracy of the Loran-C system makes it a suitable candidate for many land radiolocation applications. The purely numeric TD readings (no names, words, or narratives) are easy and efficient to both store and retrieve in automated form. Since the data are purely numeric, there can be none of the ambiguity that results from attempting to retrieve narrative descriptors from traffic accident reports and highway inventory data. While the 100 kHz signal is affected to some extent by soil

A

Table A-1. Loran-C System Characteristics (Signal-In-Space)

ACCURACY (2 drms)		AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE							
0.25nm (460m) 1:3 SNR	60-300 ft. (18-90m)	99+%	U.S. coastal areas, continental U.S., selected overseas areas	99.7%*	1 O-20 fixes/min.	2D	Unlimited	Yes, easily resolved

* *Triad reliability.*

SYSTEM DESCRIPTION: Loran-C is a Low Frequency (LF) 100kHz hyperbolic radionavigation system. The receiver computes lines of position (LOP) based on the time of arrival difference between two time-synchronized transmitting stations of a chain. Three stations are required (master and two secondaries) to obtain a position fix in the normal mode of operation. Loran-C can be used in the Rho-Rho mode and accurate position data can be obtained with only two stations, Rho-Rho requires that the user platform have a precise clock. The United States is the primary provider of Loran-C coverage, although several nations in Europe and the Middle East have or are planning to initiate Loran-C service.

conductivity and terrain, it can be received in mountainous areas (where VHF and UHF systems can be terrain limited); however, some distortion of the hyperbolic grid has been noted. Propagation anomalies may be encountered in urban areas where the proximity of large manmade structures affects the signal. The existence of these anomalies is predictable and can be compensated for, usually by surveying the area. The long range of the Loran-C system makes it particularly desirable for application to remote areas, or where the user population is too low to justify the cost of a large number of short-range facilities.

By monitoring Loran-C signals at a fixed site, the receiver TD can be compared with a computed TD for the known location of the site. A correction for the area can then be broadcast to users. This technique (called differential Loran-C), whereby real-time corrections are applied to Loran-C TD readings, provides improved accuracy. Although this can improve Loran-C's absolute accuracy features, no investment in this approach to enhancing Loran-C's performance is anticipated by the Federal Government.

Loran-C signal monitors have been installed throughout the NAS to support the use of Loran-C as a nonprecision approach aid. The monitors will be operated and maintained by the FAA. Each monitor will provide long-term signal data for use in the prediction of signal corrections at individual airports. Predicted corrections will be published periodically with approach procedures. Signal status information will be used by air traffic personnel as necessary.

Loran-C receivers are available at a relatively low cost and achieve the 0.25 nm (2 drms) accuracy that Loran-C provides at the limits of the coverage area. A modem Loran-C receiver automatically acquires and tracks the Loran-C signal and is useful to the limits of the specified Loran-C coverage areas.

C. Availability

The Loran-C transmitting equipment is very reliable. Redundant transmitting equipment is used to reduce system downtime, Loran-C transmitting station signal availability is greater than 99.9 percent, providing 99.7 percent triad availability.

D. Coverage

The Loran-C system has been expanded over the years to meet the requirements for coverage of the U.S. coastal waters and the conterminous 48 states, the Great Lakes, the Gulf of Alaska, the Aleutians, and into the Bering Sea. Based on DOD requirements, the USCG also operates Loran-C stations in the Far East, Northern Europe, and the Mediterranean Sea. Loran-C coverage as it will be operated and supported by the USCG after January 1, 1995 is shown in Figure A- 1.

Expansion of the Loran-C system into the Caribbean Sea, the North Slope of Alaska, and Eastern Hawaii has been investigated. Studies have shown, however, that the

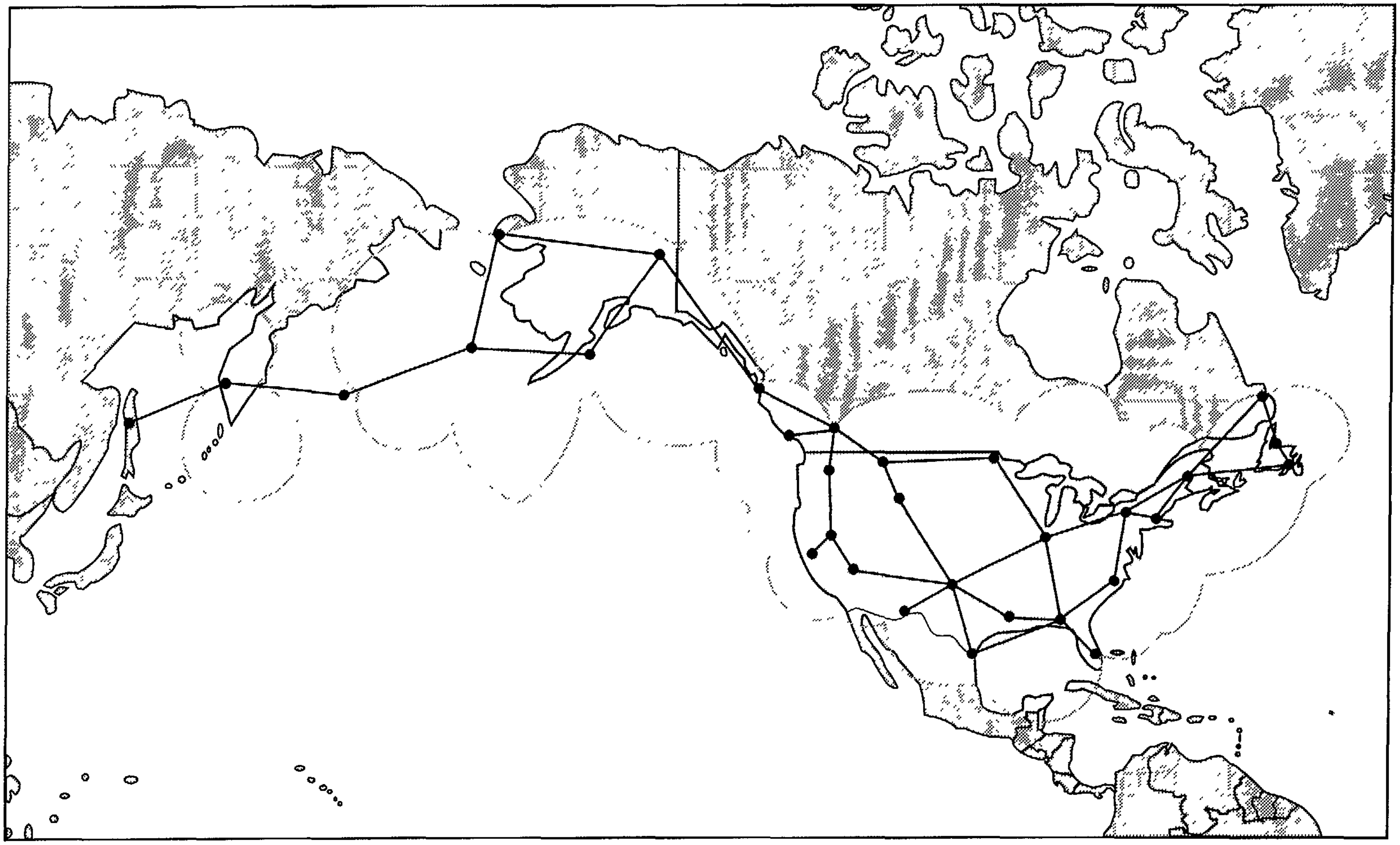


Figure A-1. Coverage Provided by U.S. Operated or Supported Loran-C Stations

benefit/cost ratio is currently insufficient to justify expansion of Loran-C into any of these areas.

E. Reliability

Loran-C stations are constantly monitored. The accuracy of system timing is maintained to half the system tolerance. Stations which exceed the system tolerance are "blinked." Blink is the on-off pattern of the first two pulses of the secondary signal indicating that a baseline is unusable. System tolerance within the U.S. is ±100 nanoseconds of the calibrated control value. Individual station reliability normally exceeds 99.9 percent, resulting in triad availability exceeding 99.7 percent. The introduction of the Automatic Blink System into the NAS will automate the method to initiate system blink. Once installed, "blink" will occur within ten seconds of a timing abnormality at a secondary station and in the case of a Master station timing abnormality, the signal will be taken off-air until the situation has been corrected or until all of the secondaries are blinking.

F. Fix Rate

The fix rate available from Loran-C ranges from 10 to 20 fixes per minute.

G. F'ix Dimensions

Loran-C will furnish two or more lines of position (LOPs) to provide a two-dimensional fix.

H. System Capacity

An unlimited number of receivers may use Loran-C simultaneously.

I. Ambiguity

As with all hyperbolic systems, theoretically, the LOPs may cross at more than one position on the earth. However, because of the design of the coverage area, the ambiguous fix is at a great distance from the desired fix and is easily resolved.

J. Integrity

Loran-C stations are constantly monitored to detect signal abnormalities which would render the system unusable for navigation purposes. The secondary stations "blink" to notify the user that a master-secondary pair is unusable. Blink begins immediately upon detection of an abnormality. The USCG and the FAA are also developing automatic blink equipment and a concept of operations based on factors consistent with aviation use. Once automatic blink equipment is installed in the NAS, secondary blink will be initiated within ten seconds of a timing abnormality and in the case of a Master station, the signal will be taken off-air until the problem is corrected and all secondaries are blinking.

A.2.2 Omega

The Omega system initially was proposed to meet a DOD need for worldwide general en route navigation but has now evolved into a system used primarily by the civil community. The system is comprised of eight continuous wave (CW) transmitting stations situated throughout the world. Worldwide position coverage was attained when the station in Australia became operational in 1982. For further information, contact the U.S. Coast Guard's Navigation Center (NAVCEN), 7323 Telegraph Road, Alexandria, Virginia, 223 15-3998 by mail, or telephone 703-3 13-5900 (voice), 703-313-5920 (fax), or 703-3 13-5906 (Omega status recording). Omega information can also be obtained via the Navigation Information Center Bulletin Board Service.

A. Signal Characteristics

Omega utilizes CW phase comparison of signal transmission from pairs of stations. The stations transmit time-shared signals on four frequencies, in the following order: 10.2 kHz, 11.33 kHz, 13.6 kHz, and 11.05 kHz. In addition to these common frequencies, each station transmits a unique frequency to aid station identification and to enhance receiver performance. The signal characteristics of Omega are summarized on Table A-2. For further information on the Omega systems, consult the Omega User's Guide (available from the USCG Navigation Center, 7323 Telegraph Road, Alexandria, Virginia 223 15-3998).

B. Accuracy

The inherent accuracy of the Omega system is limited by the accuracy of the propagation corrections that must be applied to the individual receiver readings. The corrections may be in the form of predictions from tables which can be applied to manual receivers or may be stored in memory and applied automatically in computerized receivers. The system was designed to provide a predictable accuracy of 2 to 4 nm (2 drms). That accuracy depends on location, station pairs used, time of day, and validity of the propagation corrections.

Propagation correction tables and formulas are based on theoretical models calibrated to fit worldwide monitor data taken over long periods. A number of permanent monitors are maintained to assess the system accuracy on a long-term basis. The system currently provides coverage over most of the Earth. The specific accuracy attained depends on the type of equipment used as well as the time of day and the location of the user. In most cases, the accuracies attained are consistent with the 2 to 4 nm system design goal and in some cases much better accuracy is reported. A validation program conducted by the USCG indicated that the Omega system meets its design goal of 2 to 4 nm accuracy.

Although not part of any current U.S. effort, a differential Omega system has been developed and there are now differential stations in operation along the coast of

Table A-2. Omega System Characteristics (Signal-In-Space)

ACCURACY (2 drms)						FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	**REPEATABLE**	**RELATIVE***	**AVAILABILITY**	**COVERAGE**	**RELIABILITY**	**RATE**	**DIMENSION**	**CAPACITY**	**POTENTIAL**
2-4 nm (3.7-7.4km)	2-4nm (3.7-7.4km)	0.25-0.5nm (463-926m)	99+%	Worldwide continuous	97%*	1 fix to every 10 seconds	2D	Unlimited	Requires knowledge to ±36nm**

* *Three* station joint signal availability.
** *Three frequency* receiver (10.2, 11.33, *13.6kHz).*

SYSTEM DESCRIPTION: Omega is a Very Low Frequency (VLF) 10.2 - 13.6kHz hyperbolic radionavigation system. There are eight transmitting stations. Position information is obtained by measuring relative phase difference of received Omega signals. The system is multinational, operated by seven nations, with day-to-day operational control exercised by the U.S. Coast Guard.

Europe, in the Mediterranean, and in Southeast Asia areas. Differential Omega stations operate on the principle of a local area monitor system comparing the received Omega signal with the predicted signal for the location and then transmitting a correction factor based on the observed difference. The correction factor is usually transmitted over an existing radiobeacon system and can provide an accuracy ranging from 0.3 nm at 50 miles to 1 nm at 500 miles. The range of transmission of the correction factor varies with the range of the beacon, but is roughly three times the advertised range of the beacon. Reception of the differential Omega signal requires the use of a differential Omega receiver.

C. Availability

Exclusive of infrequent periods of scheduled off-air time for maintenance, Omega availability is greater than 99 percent per year for each station and 95 percent for three stations. Annual system availability has been greater than 97 percent with scheduled off-air time included.

D. Coverage

Omega provides essentially worldwide coverage.

E. Reliability

Omega system design requirements for reliability called for 99 percent single station availability and 95 percent three-station joint signal availability. Three-station joint signal availability exceeds 97 percent, including both emergency shutdowns and scheduled off-air periods.

F. Fix Rate

Omega provides independent positional fixes once every ten seconds.

G. Fix Dimensions

Omega will furnish two or more LOPs to provide a two-dimensional fix.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

In this CW system, ambiguous LOPs occur since there is no means to identify particular points of constant phase difference which recur throughout the coverage area. The area between lines of zero phase difference are termed “lanes.” Single-frequency receivers use the 10.2 kHz signals whose lane width is about eight nautical miles on the baseline between stations. Multiple-frequency receivers extend the lane width, for the purpose of resolving lane ambiguity. Lane widths of approximately 288 nm along the baseline can be generated with a four-frequency receiver. Because of the lane ambiguity, a receiver must be preset to a known location at the start of a voyage. The accuracy of that position must be known with sufficient accuracy to be within the lane that the receiver is capable of generating (i.e., 4 nm for a single-frequency receiver or approximately 144 nm for a four-frequency receiver). Once set to a known location, the Omega receiver counts the number of lanes it crosses in the course of a voyage. This lane count is subject to errors which may be introduced by an interruption of power to the receiver, changes in propagation conditions near local sunset and sunrise, and other factors. To use the single frequency Omega receiver effectively for navigation, it is essential that a DR plot or similar means be carefully maintained and the Omega positions compared to it periodically so that any lane ambiguities can be detected and corrected.

The accuracy of an Omega phase-difference measurement is independent of the elapsed time or distance since the last update. Unless the Omega position is verified occasionally by comparison to a fix obtained with another navigation system or by periodic comparison to a carefully maintained plot, the chance of an error in the Omega lane count increases with time and distance. These errors are reduced in multiple frequency receivers since they are capable of developing larger lane widths to resolve ambiguity problems.

J. Integrity

Omega transmissions are monitored constantly to detect signal abnormalities that affect the useable coverage area. Emergency advisories for unplanned status changes (reduced power, off-airs, Polar Cap Absorption, etc.) are provided by the Navigation Center within 24 hours. This notification is distributed by the National Bureau of Standards (WWV/WWVH announcements), Broadcast Notice to Mariners, Notice to Airmen, HYDROLANT/HYDROPAC messages through the Navigation Information Services, and recorded telephone messages. Scheduled off-air periods are announced up to 30 days before the off-air is to occur using the same distribution mechanisms as for unplanned status changes.

A.2.3 VOR, VOR/DME, and TACAN

The three systems that provide the basic guidance for en route air navigation in the United States are VOR, DME, and TACAN. Information provided to the aircraft pilot by VOR is the azimuth relative to the VOR ground station. DME provides a measurement of distance from the aircraft to the DME ground station. In most cases, VOR and DME are collocated as a VOR/DME facility. TACAN provides both azimuth and distance information and is used primarily by military aircraft. When TACAN is collocated with VOR, it is a VORTAC facility. DME and the distance measuring function of TACAN are the same.

I. VOR

A. Signal Characteristics

VORs are assigned frequencies in the 108 to 118 MHz frequency band, separated by 100 kHz. A VOR transmits two 30 Hz modulations resulting in a relative electrical phase angle equal to the azimuth angle of the receiving aircraft. A cardioid field pattern is produced in the horizontal plane and rotates at 30 Hz. A nondirectional (circular) 30 Hz pattern is also transmitted during the same time in all directions and is called the reference phase signal. The variable phase pattern changes phase in direct relationship to azimuth. The reference phase is frequency modulated while the variable phase is amplitude modulated. The receiver detects these two signals and computes the azimuth from the relative phase difference. For difficult siting situations, a system using the Doppler effect was developed and uses 50 instead of four antennas for the variable phase. The same avionics works with either type ground station. The signal characteristics of VOR are summarized in Table A-3.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are approximately ±1.4 degrees. The addition of course selection, receiver and flight technical errors, when combined using root-sum-squared (RSS) techniques, is calculated to be ±4.5 degrees.

- Relative - Although some course bending could influence position readings between aircraft, the major relative error consists of the course selection, receiver and flight technical components. When combined using RSS techniques, the value is approximately ±4.3 degrees. The VOR ground station relative error is ±0.35 degrees.

- Repeatable - The major error components of the ground system and receiver will not vary appreciably in the short term. Therefore, the repeatable error will consist mainly of the flight technical error (the pilots' ability to fly the system) which is ±2.3 degrees.

C. Availability

Because VOR coverage is overlapped by adjacent stations, the availability is considered to approach 100 percent for new solid state equipment.

D. Coverage

VOR has line-of-sight limitations which could limit ground coverage to 30 miles or less. At altitudes above 5,000 feet, the range is approximately 100 nm, and above 20,000 feet, the range will approach 200 nm. These stations radiate approximately 200 watts. Terminal VOR stations are rated at approximately 50 watts and are only

Table A-3. VOR and VOR/DME System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma) PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
VOR: 90m ($\pm$1.4°)*	**23m ($\pm$0.35°)****	–	**Approaches 100%**	tine of sight	Approaches 100%	**Continuous**	Heading in degrees or angle off course	Unlimited	**None**
DME: 185m ($\pm$0.1nm)	**185m ($\pm$0.1nm)**	–					Slant range (nm)	100 users per site, full service	

* *The flight check of published procedures for the VOR* signal is *±1.4°. The ground monitor turns the system off if the signal exceeds ±1.0°.*
The cross-track error used in the chart is for ±1.4° at 2nm from the VOR site. However, some uses of VOR are overhead and/or 1/2nm from the VOR.

** *Test data shows that 99.94% of the time the error is less than ±.35°. These values are for ±.35° at 2nm from the VOR.*

SYSTEM DESCRIPTION: VOR provides aircraft with bearing information relative to the VOR signal and magnetic north. The system is used for landing, terminal, and en route guidance. VOR transmitters operate in the VHF frequency range. DME provides a measurement of distance from the aircraft to the DME ground station. DME operates in the UHF frequency range.

intended for use within the terminal areas. Actual VOR coverage information is contained in FAA Order 1010.55C.

E. Reliability

Due to advanced solid state construction and the use of remote maintenance monitoring techniques, the reliability of solid state VOR approaches 100 percent.

F. Fix Rate

This system allows a continuous update of deviation from a selected course. Initialization is less than one minute after turn-on and will vary as to receiver design.

G. F&Dimensions

The system shows magnetic bearing to a VOR station and deviation from a selected course, in degrees.

H. System Capacity

The capacity of a VOR station is unlimited.

I. Ambiguity

There is no ambiguity possible for a VOR station.

J. Integrity

VOR provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

II. DME

A. Signal Characteristics

The interrogator in the aircraft generates a pulsed signal (interrogation) which, when of the correct frequency and pulse spacings, is accepted by the transponder. In turn, the transponder generates pulsed signals (replies) which are sent back and accepted by the interrogator’s tracking circuitry. Distance is then computed by measuring the total round trip time of the interrogation and its reply. The operation of DME is thus accomplished by paired pulse signals and the recognition of desired pulse spacings accomplished by the use of a decoder. The transponder must reply to all interrogators. The interrogator must measure elapsed time between interrogation and reply pulse pairs and translate this to distance. All signals are vertically polarized. These systems are assigned in the 960 to 1,213 MHz frequency band with a separation of 1 MHz.

The capability to use Y-channel service has been developed and implemented to a very limited extent (approximately 15 DMEs paired with localizers use the Y-channel frequencies). The term "Y-channel" refers to VOR frequency spacing. Normally, X-channel frequency spacing of 100 kHz is used. Y-channel frequencies are offset from the X-channel frequencies by 50 kHz. In addition, Y-channel DMEs are identified by a wider interrogation pulse-pair time spacing of 0.036 msec versus X-channel DMEs at 0.012 msec spacing. X- and Y-channel applications are presently limited to minimize user equipment changeovers. The signal characteristics of DME are summarized in Table A-3.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±0.1 nm. The overall system error (airborne and ground RSS) is not greater than ±O.5 nm or 3 percent of the distance, whichever is greater.

- Relative - Although some errors could be introduced by reflections, the major relative error emanates from the receiver and flight technical error.

- Repeatable- Major error components of the ground system and receiver will not vary appreciably in the short term.

C. Availability

The availability of DME is considered to approach 100 percent, with positive indication when the system is out-of-tolerance.

D. Coverage

DME has a line-of-sight limitation, which limits ground coverage to 30 nm or less. At altitudes above 5,000 feet, the range will approach 100 nm. En route stations radiate at 1,000 watts. Terminal DMEs radiate 100 watts and are only intended for use in terminal areas.

E. Reliability

With the use of solid state components and remote maintenance monitoring techniques, the reliability of the DME approaches 100 percent.

F. Fix Rate

The system essentially gives a continuous update of distance to the facility. Actual update rate varies with the design of airborne equipment and system loading.

G. Fix Dimensions

The system shows slant range to the DME station in nm.

H. System Capacity

For present traffic capacity 1 IO interrogators are considered reasonable. Future traffic capacity could be increased when necessary through reduced individual aircraft interrogation rates and removal of beacon capacity reply restrictions.

I. Ambiguity

There is no ambiguity in the DME system.

J. Integrity

DME provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

III. TACAN

A. Signal Characteristics

TACAN is a short-range UHF (960 to 1,215 MHz) radionavigation system designed primarily for aircraft use. TACAN transmitters and responders provide the data necessary to determine magnetic bearing and distance from an aircraft to a selected station. TACAN stations in the U.S. are frequently collocated with VOR stations. These facilities are known as VORTACs. The signal characteristics of TACAN are summarized in Table A-4.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±1.O degree for azimuth for the 135 Hz element and ±4.5 degrees for the 15 Hz element. Distance errors are the same as DME errors.

- Relative - The major relative errors emanate from course selection, receiver and flight technical error.

- Repeatable - Major error components of the ground station and receiver will not vary greatly in the short term. The repeatable error will consist mainly of the flight technical error.

C. Availability

The availability of TACAN service is considered to approach 100 percent.

D. Coverage

TACAN has a line-of-sight limitation which limits ground coverage to 30 nm or less. At altitudes of 5,000 feet the range will approach 100 nm; above 18,000 feet, the range approaches 200 nm. The station output power is 5 kW.

Table A-4. TACAN System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Azimuth +1^{0} (±63m at 3.75km)	Azimuth +1^{0} (±63m at 3.75km)	Azimuth ±1^{0} (±63m at 3.75km)	98.7%	Line of sight	99%	Continuous	Distance and bearing from station	110 for distance. Unlimited in azimuth	No ambiguity in range. Sight potential for ambiguity at multiples of 40^{0}
DME: 185m (±0.1nm)	DME: 185m (±0.1nm)	DME: 185m (±0.1nm)							

SYSTEM DESCRIPTION: TACAN is a short-range UHF navigation system used by the military. The system provides range, bearing and station identification. When TACAN is collocated with a VOR it is called a VORTAC facility.

E. Reliability

With the use of solid state electronics and remote maintenance monitoring techniques, the reliability of the TACAN system approaches 100 percent.

F. Fix Rate

TACAN provides a continuous update of the deviation from a selected course. Initialization is less than one minute after turn on. Actual update rate varies with the design of airborne equipment and system loading.

G. Fix Dimensions

The system shows magnetic bearing, deviation in degrees, and distance to the TACAN station in nautical miles.

H. System Capacity

For distance information, 110 interrogators are considered reasonable for present traffic handling. Future traffic handling could be increased when necessary through reduced airborne interrogation rates and increased reply rates. Capacity for the azimuth function is unlimited.

1. Ambiguity

There is no ambiguity in the TACAN range information. There is a slight probability of azimuth ambiguity at multiples of 40 degrees.

J. Integrity

TACAN provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

A.2.4 ILS

ILS is a precision approach system normally consisting of a localizer facility, a glide slope facility, and two or three VHF marker beacons. It provides vertical and horizontal navigational (guidance) information during the approach to landing at an airport runway.

At present, ILS is the primary worldwide, ICAO-approved, precision landing system. This system is presently adequate, but has limitations in siting, frequency allocation, cost, and performance.

A. Signal Characteristics

The localizer facility and antenna are typically located 1,000 feet beyond the stop end of the runway and provides a VHF (108 to 112 MHz) signal. The glide slope facility is located approximately 1,000 feet from the approach end of the runway and provides a UHF (328.6 to 335.4 MHz) signal. Marker beacons are located along an extension of the runway centerline and identify particular locations on the approach. Ordinarily, two 75 MHz beacons are included as part of the instrument landing system: an outer marker at the initial approach fix (typically four to seven miles from the approach end of the runway) and a middle marker located 3,500 feet plus or minus 250 feet from the runway threshold. The middle marker is located so as to note impending visual acquisition of the runway in conditions of minimum visibility for Category I ILS approaches. An inner marker, located approximately 1,000 feet from the threshold, is normally associated with Category II and III ILS approaches. The signal characteristics of ILS are summarized in Table A-5.

B. Accuracy

For typical air carrier operations at a 10,000 foot runway, the course alignment (localizer) at threshold is maintained within ±25 feet. Course bends during the final segment of the approach do not exceed ±0.06 degrees (2 sigma). Glide slope course alignment is maintained within ±7.0 feet at 100 feet (2 sigma) elevation and glide path bends during the final segment of the approach do not exceed ±0.07 degrees (2 sigma).

C. Availability

To further improve the availability of service from ILS installations, vacuum tube equipment has been replaced with solid state equipment. Service availability is now approaching 99 percent.

D. Coverage

Coverage for individual systems is as follows:

Localizer: $\pm 2^{o}$ centered about runway centerline.

Glide Slope: Nominally $\pm 3^{o}$ above the horizontal.

Marker Beacons: $\pm 40^{o}$ (approximately) on minor axis (along approach path) $\pm 85^{o}$ (approximately) on major axis.

E. Reliability

ILS reliability approaches 100 percent. However, terrain and other factors may impose limitations upon the use of the ILS signal. Special account must be taken of terrain factors and dynamic factors such as taxiing aircraft which can cause multipath signal transmissions.

In some cases, to resolve ILS siting problems, use has been made of localizers with wide aperture antennas and two-frequency systems. In the case of the glide slope,

Table A-5. ILS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)									
CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
1	±9.1	±3.0	Approaches 100%	Normal limits from center of localizer ± 10^{0} out to 18nm and ±35^{0} out to 10nm	98.6% with positive indication when the system is out of tolerance	Continuous	Heading and deviation in degrees	Limited only by aircraft separation requirements	None
2	4.6	±1.4							
3	54.1	±0.4							

* *Signal* availability in the coverage volume.

SYSTEM DESCRIPTION: The Instrument Landing System (ILS) is a precision approach system consisting of a localizer facility, a glide scope facility and two or three VHF marker beacons. The VHF (108-112Mhz) localizer facility provides accurate, single path horizontal guidance information. The UHF (328.6-335.4Mhz) glide scope provides precise, single path, vertical guidance information to a landing aircraft.

use has been made of wide aperture, two-frequency image arrays and single-frequency broadside arrays to provide service at difficult sites.

F. Fix Rate

The glide slope and localizer provide continuous fix information. Marker beacons which provide an audible and visual indication to the pilot are sited at specific points along the approach path as indicated in Table A-6.

Table A-6. Aircraft Marker Beacons

MARKER DESIGNATION	TYPICAL DISTANCE TO THRESHOLD	AUDIBLE SIGNAL	LIGHT COLOR
Outer	4-7nm	Continuous dashes (2/sec))	Blue
Middle	3,250-3,750 ft	Continuous alternating dot-dash	Amber
Inner	1,000 ft	Continuous dots (6/sec))	White

G. Fix Dimensions

ILS provides both vertical and horizontal guidance with glide slope and localizer signals. At periodic intervals (passing over marker beacons) distance to threshold is obtained.

H. System Capacity

ILS has no capacity limitations except those imposed by aircraft separation requirements since aircraft must be in trail to use the system.

I. Ambiguity

Any potential ambiguities are resolved by imposing system limitations as described in Section A.2.4.E.

J. Integrity

ILS provides system integrity by removing a signal from use when an out-of-tolerance condition is detected by an integral monitor. The shutdown delay for each category is given below:

Shutdown Delay

	Localizer	Glide Slope
CAT I	<10 sec	<6 sec
CAT II	***<5 sec***	***<2 sec***
CAT III	***<2 sec***	***<2 sec***

A.2.5 MLS

MLS provides a common civil/military landing system to meet the full range of user operational requirements, as defined in the ICAO list of 38 operational requirements for precision approach and landing systems, to the year 2000 and beyond. It was originally intended to be a replacement for ILS, used by both civil and military aircraft, and the Ground Controlled Approach (GCA) system used primarily by military operators. However, DGPS systems are now envisioned to satisfy the majority of requirements originally earmarked for MLS.

The FAA has terminated all R,E&D activity associated with MLS and has limited deployment to approximately 30 Category I sites at airports supporting international operations that can be satisfied with MLS systems manufactured through June 1994. The role of MLS in support of Category II and III requirements is to be determined pending architectural decisions scheduled for late 1995.

For those MLS systems that are ultimately deployed, the MLS signal is transmitted throughout a large volume of airspace, thereby permitting service to multiple aircraft, along multiple approach paths, throughout the approach, flare, touchdown, and rollout maneuvers. The system permits greater flexibility in air traffic procedures, enhancing safety, and permits curved and segmented approach paths for purposes of noise abatement. MLS allows steep glide path approaches for airports in mountainous terrain, and facilitates short field operations for short and/or vertical takeoff and landing (STOL and VTOL) aircraft.

A. Signal Characteristics

MLS transmits signals that enable airborne units to determine the precise azimuth angle, elevation angle, and range. The technique chosen for the angle function of the MLS is based upon Time-Referenced Scanning Beams (TRSB). All angle functions of MLS operate in the 5.00 to 5.25 GHz band. Ranging is provided by DME operating in the 0.96 to 1.215 GHz band. An option is included in the signal format to permit a special purpose system to operate in the 15.4 to 15.7 GHz band. The system characteristics of MLS are summarized in Table A-7.

Table A-7. MLS Characteristics (Signal-In-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma) CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
1	±9.1	±3.0	Expected to approach 100%	40^0 from center line of runway out to 20nm in both directions*	Expected to approach 100%	**6.5-39 fixeslsec** depending on function	Heading and deviation in degrees. Range in nm	Limited only by aircraft separation requirements	None
2	±4.6	±1.4							
3	±4.1	±0.4							

* *There are provisions for 360^0 out to 20nm.*

SYSTEM DESCRIPTION: The Microwave Landing System (MLS) is a precision landing system that will operate in the 5-5.25 GHz band. Ranging is provided by precision DME operating in .96-1.22 GHz band.

B. Accuracy (2 sigma)

The azimuth accuracy is ±13.0 feet (±4.0m) at the runway threshold approach reference datum and the elevation accuracy is ±2.0 feet (±.6m). The lower surface of the MLS beam crosses the threshold at 8 feet (2.4 meters) above the runway centerline. The flare guidance accuracy is ±1.2 feet throughout the touchdown zone and the DME accuracy is ±100 feet for the precision mode and ±1,600 feet for the nonprecision mode.

C. A vailability

Equipment redundancy, as well as remote maintenance monitoring techniques, should allow the availability of this system to approach 100 percent.

D. Coverage

Current plans call for the installation of systems with azimuthal coverage of ±40° on either side of the runway centerline, elevation coverage from 0^{o} to a minimum of 15” over the azimuthal coverage area, and out to 20 nm. A few systems will have ±60” azimuthal coverage. MLS signal format has the capability of providing coverage to the entire 360^{o} area but with less accuracy in the area outside the primary coverage area of ±60° of runway centerline. There will be simultaneous operations of ILS and MLS during the transition period.

E. Reliability

The MLS signals are generally less sensitive than ILS signals to the effects of snow, vegetation, terrain, structures, and taxiing aircraft. This allows the reliability of this system to approach 100 percent.

F. Fix Rate

Elevation angle is transmitted at 39 samples per second, azimuth angle at 13 samples per second, and back azimuth angle at 6.5 samples per second. Usually the airborne receiver averages several data samples to provide fixes of 3 to 6 samples per second. A high rate azimuth angle function of 39 samples per second is available and is normally used where there is no need for flare elevation data.

G. Fix Dimensions

This system provides signals in all three dimensions and can provide time if aircraft are suitably equipped.

H. System Capacity

DME signals of this system are capacity limited; the system limits are approached when 110 aircraft are handled.

I. Ambiguity

No ambiguity is possible for the azimuth or elevation signals. Only a very small probability for ambiguity exists for the range signals and then only for multipath caused by moving reflectors.

J. Integrity

MLS integrity is provided by an integral monitor. The monitor shuts down the MLS within one second of an out-of-tolerance condition.

A.2.6 Transit

Transit is a space-based radiodetermination system consisting of satellites in approximately 600 nm polar orbits. The phasing of the satellites is deliberately staggered to minimize time between fixes for users. In addition, Transit has four ground-based monitors. The monitor stations track each satellite while in view and provide the tracking information necessary to update satellite orbital parameters every 12 hours.

A. Signal Characteristics

The satellites broadcast ephemeris information continuously on 150 and 400 MHz. One frequency is required to determine a position. However, by using the two frequencies, higher accuracy can be attained. A receiver measures successive Doppler, or apparent frequency shifts of the signal, as the satellite approaches or passes the user. The receiver then calculates the geographic position of the user based on knowledge of the satellite position that is transmitted from the satellite every two minutes, and knowledge of the doppler shift of the satellite signal. The characteristics of Transit are summarized in Table A-8.

B. Accuracy

Predictable positioning accuracy is 500 meters for a single frequency receiver and 25 meters for a dual frequency receiver. Repeatable positioning accuracy is 50 meters for a single frequency and 15 meters for a dual frequency receiver. Relative positioning accuracy of less than 10 meters has been measured through translocation techniques. Navigational accuracy is heavily dependent upon the accuracy to which vessel course, speed, and time are known. A one knot velocity input error can cause up to 0.2 nm fix error.

C. Availability

Availability is better than 99 percent when a Transit satellite is in view. It depends on user latitude, antenna mask angle, user maneuvers during a satellite pass, the number of operational satellites and satellite configuration.

Table A-8. Transit System Characteristics (Signal-In-Space)

ACCURACY* (Meters-2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE**	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Dual frequency 25m	15m	Under 10m with translocation techniques	99% when satellite is in view	Worldwide noncontinuous	99%	Every 30 seconds	2D	Unlimited	None
Single frequency 500m	50m								

* Position accuracy is high/y dependent on the user's knowledge of his velocity.

** Maximum satellite waiting time varies with latitude. (30 seconds at 80° 110 minutes at equator)

SYSTEM DESCRIPTION: Transit nominally consists of four operational satellites in polar orbits, The satellites broadcast information on 150 and 400 Mhz. A receiver measures the apparent frequency shift of the signals (Doppler) as the satellite approaches and passes the user. The receiver then calculates the geographic position of the user, based on satellite position knowledge and corrections received from the transmitted signal.

D. Coverage

Coverage is worldwide but not continuous due to the relatively low altitude of the Transit satellites and the precession of satellite orbits.

E. Reliability

The reliability of the Transit satellites is greater than 99 percent.

F. Fix Rate

Fix rate varies with latitude, theoretically from an average of 110 minutes at the equator to an average of 30 minutes at 80 degrees. Presently, due to non-uniform orbital precession, the Transit satellites are no longer in evenly spaced orbits. Consequently, a user can occasionally expect a period greater than 6 hours between fixes. This condition exists for less than 5 percent of system availability.

G. Fix Dimensions

Transit satellites provide a two-dimensional fix.

H. System Capacity

Transit satellites have unlimited capacity.

I. Ambiguity

There is no ambiguity.

J. Integrity

Transit satellite signals are monitored by the Naval Astronautics Group (NAG) at Point Mugu, California, which serves as the satellite constellation ground control facility. Whenever a satellite-transmitted signal is out-of-tolerance or otherwise unsuitable for use, NAG will issue a "SPATRAK" alerting message to all known U.S. Navy Transit users, with an information copy to DMA. DMA then ensures that the alert is entered into the Notice to Mariners system for distribution to civil users. The same procedure is used for scheduled test or preventative maintenance periods on selected satellites. Transit receivers do not possess inherent signal integrity monitoring capabilities, other than the ability to recognize and reject the scrambled signal format broadcast by selected satellites during certain NAG-implemented system tests.

A.2.7 Aeronautical *Radiobeacons*

Radiobeacons are nondirectional radio transmitting stations which operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. A radio direction finder (RDF) is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

Presently, there are 1,575 low- and medium-frequency aeronautical nondirectional beacons (NDBs). These are distributed as follows: FAA-operated Federal facilities: 728; non-Federally owned facilities: 847. Little change in the navigational status of the civil facilities is expected before the year 2000.

A. Signal Characteristics

Aeronautical NDBs operate in the 190 to 415 kHz and 5 10 to 535 kHz bands. Their transmissions include a coded continuous-wave (CCW) or modulated continuous-wave (MCW) signal to identify the station. The CCW signal is generated by modulating a single carrier with either a 400 Hz or a 1,020 Hz tone for Morse code identification. The MCW signal is generated by spacing two carriers either 400 Hz or 1,020 Hz apart and keying the upper carrier to give the Morse code identification. The characteristics of aeronautical NDBs are summzarized in Table A-9.

B. Accuracy

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of ±3 to ±l 0 degrees. Achievement of ±3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations. For FAA flight inspection, NDB system accuracy is stated in terms of permissible needle swing: ±5 degrees on approaches and ±lO degrees in the en route area.

C. Availability

Availability of aeronautical NDBs is in excess of 99 percent.

D. Coverage

Extensive NDB coverage is provided by 1,575 ground stations, of which the FAA operates 728.

Table A-9. Radiobeacon System Characteristics (Signal-In-Space)

ACCURACY (2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Aeronautical **$\pm 3\text{-}10^{o}$**	N/A	N/A	99%	Maximum service volume - 75nm	99%	Continuous	One LOP per beacon	Unlimited	Potential is high for reciprocal bearing without sense antenna
Marine **$\pm 3^{o}$**	N/A	N/A	99%	Out to 50nm or 100 fathom curve					

SYSTEM DESCRIPTION: Aircraft nondirectional beacons are used to supplement VOR-DME for transition from en route to airport precision approach facilities and as a nonprecision approach aid at many airports. Only low frequency beacons are considered in the FRP since there is little common use of the VHF/UHF beacons. Marine radiobeaccns are used as homing beacons to identify the entrance to harbors, Selected marine beacons carry differential GPS data.

E. Reliability

Reliability is in excess of 99 percent.

F. Fix Rate

The fix rate is a function of whether the beacon is continuous or sequenced. In general, at least one line of position, or relative bearing, is provided continuously. If sequenced, fixing a position may require up to six minutes, depending on the LOPs selected. The modernization effort will convert each radiobeacon to continuous service which will improve the fix rate.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon. If within one range of two or more beacons, a fix may be obtained.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

1. Ambiguity

The only ambiguity which exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment which does not employ a sense antenna to resolve direction.

J. Integrity

A radiobeacon is an omnidirectional navigational aid. For aviation radiobeacons, out-of-tolerance conditions are limited to output power reduction below operating minimums and loss of the transmitted station identifying tone. The radiobeacons used for nonprecision approaches are monitored and will shut down within 15 seconds of an out-of-tolerance condition.

A. 2.8 *Maritime* Radiobeacons

Radiobeacons are nondirectional radio transmitting stations which operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. An RDF is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

There are approximately 85 USCG-operated marine radiobeacons. Some maritime radiobeacons will be modified to carry differential GPS correction signals. These maritime radiobeacons will remain part of the radionavigation systems mix into the next century. The remaining marine radiobeacons are expected to be phased out by the year 2000.

A. Signal Characteristics

Marine radiobeacons operate in the 285 to 325 kHz band. The signal characteristics for marine radiobeacons are summarized in Table A-9. Radiobeacons used for DGPS will be modulated with minimum shift keying (MSK) modulation to broadcast DGPS corrections (see section A.2.10.1). In addition, radiobeacons may be operated in a single carrier mode resulting in the elimination of the Morse code identifier. A decision on the single carrier operation will be made by 1996.

B. Accuracy

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of ±3 to ±lO degrees. Achievement of ±3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations.

C. Availability

Availability of marine radiobeacons is in excess of 99 percent.

D. Coverage

The coverage of marine radiobeacons is changing as radiobeacons with little to no identified users are discontinued.

E. Reliability

Reliability is in excess of 99 percent. Radiobeacons used for DGPS broadcasts will have reliability in excess of 99.7 percent.

F. Fix Rate

The fix rate is provided continuously.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon. If within range of two or more beacons, a fix may be obtained.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

The only ambiguity which exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment which does not employ a sense antenna to resolve direction.

J. Integrity

A radiobeacon is an omnidirectional navigational aid. Marine radiobeacons are monitored either continuously or periodically, depending on equipment configuration. Radiobeacons broadcasting operational DGPS corrections are monitored continuously. Notification of outages is provided by a broadcast Notice to Mariners. Outages of long duration are announced in both the Local Notice to Mariners and the Notice to Mariners.

A.2.9 *GPS*

GPS is a space-based radionavigation system which is managed for the Government of the United States by the U.S. Air Force, the system operator. GPS was originally developed as a military force enhancement system and will continue to play this role; however, GPS also has significant potential to benefit the civil community in an increasingly large number and variety of applications. In an effort to make GPS service available to the greatest number of users while ensuring that national security interests of the United States are protected, two GPS services are provided. The Precise Positioning Service (PPS) provides full system accuracy primarily to U.S. and allied military users. The Standard Positioning Service (SPS) is designed to provide accurate positioning capability for civil users throughout the world. The GPS has three major segments: space, control, and user.

The GPS Space Segment is composed of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period. The spacing of satellites in orbit are arranged so that a minimum of 5 satellites are in view to users worldwide, with a Position of Dilution (PDOP) of six or less.

The GPS Control Segment has five monitor stations and three ground antennas with uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the Master Control Station (MCS) to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for transmitting and receiving health and control information.

The GPS User Segment consists of a variety of configurations and integration architectures that include an antenna and receiver-processor to receive and compute navigation solutions to provide positioning, velocity, and precise timing to the user.

A. Signal Characteristics

Each satellite transmits three separate spectrum signals on two L-band frequencies, Ll (1575.42 MHz) and L2 (1227.6 MHz). Ll carries a Precise P (Y) Pseudo-Random Noise (PRN) code and a Coarse/Acquisition (C/A) PRN code; L2 carries the P(Y) PRN code. (The Precise code is denoted as P(Y) to identify that this PRN code can be operated in either a clear unencrypted “P” or an encrypted “Y” code configuration.) Both PRN codes carried on the Ll and L2 frequencies are phase-synchronized to the satellite clock and modulated (using modulo two addition) with a common 50 Hz navigation data message.

In order to support civil GPS applications, the SPS user is guaranteed system access through the use of the Ll C/A signal while the P(Y) code on Ll and L2 is reserved for PPS requirements. The SPS signal received by the user is a spread spectrum signal centered on Ll with a 2.046 MHz bandwidth. Minimum SPS received power is specified as -160.0 dBW. The navigation data contained in the signal is composed of satellite clock and ephemeris data for the transmitting satellite plus GPS constellation almanac data, GPS to UTC time offset information, and ionospheric propagation delay correction parameters for single frequency users. The entire navigation message repeats every 12.5 minutes. Within this 12.5-minute repeat cycle, satellite clock and ephemeris data for the transmitting satellite is sent 25 separate times so it repeats every 30 seconds. As long as a satellite indicates a healthy status, a receiver can continue to operate using this data for the validity period of the data (up to 4 or 6 hours). Normally however, the receiver will update this data whenever the satellite and ephemeris information is updated - nominally once every 2 hours.

The concept of GPS position determination is based on the intersection of four separate vectors each with a known origin and a known magnitude. Vector origins for each satellite are computed based on satellite ephemeris. Vector magnitudes are calculated based on signal propagation time delay as measured from the transmitting satellite’s PRN code phase delay. Given that the satellite signal travels at nearly the speed of light and taking into account delays and adjustment factors such as ionospheric propagation delays and earth rotation factors, the receiver performs ranging measurements between the individual satellite and the user by dividing the satellite signal propagation time by the speed of light.

These measurements are combined to yield system time and the user’s three-dimensional position with respect to World Geodetic Systems, 1984 (WGS-84) Earth Centered - Earth Fixed (ECEF) coordinates. A user’s velocity can thus be computed by propagating the user’s position with respect to time. Standard coordinate transformations are then performed within the receiver to provide user position and velocity in local coordinates (e.g., North American Datum 1987 latitude, longitude, and altitude coordinates).

A stand-alone GPS receiver requires four simultaneous measurements from four satellites to determine position in three dimensions and time. The receiver uses the four simultaneous measurements to yield four linearized mathematical equations with four unknowns from which the four unknowns can be solved (e.g., latitude, longitude, altitude, and time). If the user needs only two-dimensional positioning and time determination, only three simultaneous measurements are required for three equations and three unknowns (latitude, longitude, and time). If the user needs only time determination, only one satellite measurement is required for one equation and one unknown (time). The characteristics of GPS are summarized in Table A-10.

B. Accuracy

GPS provides two services for position determination, SPS and PPS. Accuracy of a GPS fix varies with the capability of the user equipment.

1. Standard Positioning Service (SPS)

SPS is the standard specified level of positioning and timing accuracy that is available, without restrictions, to any user on a continuous worldwide basis. The accuracy of this service will be established by the DOD and DOT based on U.S. security interests. SPS provides a predictable positioning accuracy of 100 meters (95 percent) horizontally and 156 meters (95 percent) vertically and time transfer accuracy to UTC within 340 nanoseconds (95 percent).

2. Precise Positioning Service (PPS)

PPS is the most accurate direct positioning, velocity, and timing information continuously available, worldwide, from the basic GPS. This service is limited to users specifically authorized by the U.S. P(Y) code capable military user equipment provides a predictable positioning accuracy of at least 22 meters (95 percent) horizontally and 27.7 meters vertically and time transfer accuracy to UTC within 200 nanoseconds (95 percent).

C. Availability

Provided there is coverage as defined below, SPS will be available at least 99.85 percent of the time.

D. Coverage

The probability that 4 or more GPS satellites over any 24-hour interval with a PDOP of 6 or less, with at least a 5^{o} mask angle is at least 99.9 percent (global average).

Table A-l 0. GPS Characteristics (Signal-In-Space)

SPS ACCURACY (METERS) - 95%			SERVICE		SERVICE	FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	RELATIVE*	AVAILABILITY	COVERAGE	RELIABILITY	RATE	DIMENSION	CAPACITY	POTENTIAL
Horz- 100 Vert- 156 Time - 340ns	Horz - 141 Vert - 221	Horz- 1.0 Vert- 1.5	99.16%	99.90% (PDOP (6)	99.79%	Essentially continuous	3D t Time	Unlimited	None

* Receivers using the *same satellites with position solutions computed at* approximately the *same time.*

SYSTEM DESCRIPTION: GPS is a space-based radio positioning navigation system that provides three-dimensional position and time information to suitably equipped users anywhere on or near the surface of the Earth. The space segment consists of 24 satellites in 6 orbital planes of 12-hour periods. Each satellite transmits navigation data and time signals on 1575.42 and 1227.6 Mhz.

E. Reliability

Conditioned on coverage and service availability, the probability that the horizontal positioning error will not exceed 500 meters at any time is at least 99.7 percent.

F. Fix Rate

The fix rate is essentially continuous. Actual time to a first fix depends on user equipment capability and initialization with current satellite almanac data.

G. Fix Dimensions

GPS provides three-dimensional positioning when four or more satellites are available and two-dimensional positioning when only three satellites are available.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

The basic GPS must be augmented to meet current civil aviation and marine integrity requirements. Receiver Autonomous Integrity Monitoring (RAIM), a receiver software program, and DGPS are two methods of satisfying integrity requirements.

DOD GPS receivers use the information contained in the navigation and health messages, as well as self-contained satellite geometry algorithms and internal navigation solution convergence monitors, to compute an estimated figure of merit. This number is continuously displayed to the operator, indicating the estimated overall confidence level of the position information.

Both DOT and DOD have recognized the requirement for additional integrity for aviation and all other users of GPS. The development of integrity capabilities to meet flight safety requirements is underway.

A.2.10 Augmentations to GPS

GPS may exhibit variances from a predicted grid established for navigation, charting, or derivation of guidance information. This variance may be caused by propagation anomalies, errors in geodesy, accidental perturbations of signal timing, or other factors.

DGPS enhances GPS through the use of differential corrections to the basic satellite measurements. DGPS is based upon accurate knowledge of the geographic location of one or more reference stations, which is used to compute corrections to GPS parameters, error sources, and/or resultant positions. These differential corrections are then transmitted to GPS users, who apply the corrections to their received GPS signals or computed position. For a civil user of SPS, differential corrections can improve navigational accuracy from 100 meters (2 drms) to better than 7 meters (2 drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station typically tracks all satellites in view, downloads ephemeris data from them, and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution. There are two well-developed methods of handling this:

- Computing and transmitting a position correction in x-y-z coordinates, which is then applied to the user's GPS solution for a more accurate position.
- Computing pseudorange corrections for each satellite, which are then broadcast to the user and applied to the user's pseudorange measurements before the GPS position is calculated by the receiver, resulting in a highly accurate navigation solution.

The first method, in which the correction terms for the x-y-z coordinates are broadcast, requires less data in the broadcast than the second method, but the validity of those correction terms decreases rapidly as the distance from the reference station to the user increases. Both the reference station and the user receiver must use the same set of satellites for the corrections to be valid. This condition is often difficult to achieve, and limits operational flexibility.

Using the second method, an all-in-view receiver at the reference site receives signals from all visible satellites and measures the pseudorange to each. Since the satellite signal contains information on the precise satellite orbits and the reference receiver knows its position, the true range to each satellite can be calculated. By comparing the calculated range and the measured pseudorange, a correction term can be determined for each satellite. The corrections are broadcast and applied to the satellite measurements at each user's location. This method provides the best navigation solution for the user and is the preferred method. It is the method being employed by the U.S. Coast Guard DGPS Service.

An elaboration of the second method is being incorporated in the FAA's WAAS for GPS. In this system, a network of GPS reference/measurement stations at surveyed locations collects dual-frequency measurements of GPS pseudorange and pseudorange rate for all spacecraft in view, along with local meteorological conditions. These data can be processed to yield highly accurate ephemeris, ionospheric and tropospheric calibration maps, and DGPS corrections for the broadcast spacecraft ephemeris and clock offsets (including the effects of Selective Availability (SA). In the WAAS, these GPS corrections and system integrity messages will be relayed to civil users via a dedicated package on geostationary satellites. This relay technique will also support the delivery of an additional ranging signal, thereby increasing overall navigation system availability.

A.2.10.1 Maritime DGPS

Figure A-2 shows the USCG system concept using pseudorange corrections. The reference station's and the mariner's pseudorange calculations are strongly correlated. Pseudorange corrections computed by the reference station, when transmitted to the mariner in a timely manner, can be directly applied to the mariner's pseudorange computation to dramatically increase the resultant accuracy of the pseudorange measurement before it is applied within the mariner's navigation solution. The USCG DGPS prototype sites are achieving accuracies on'the order of 1 meter.

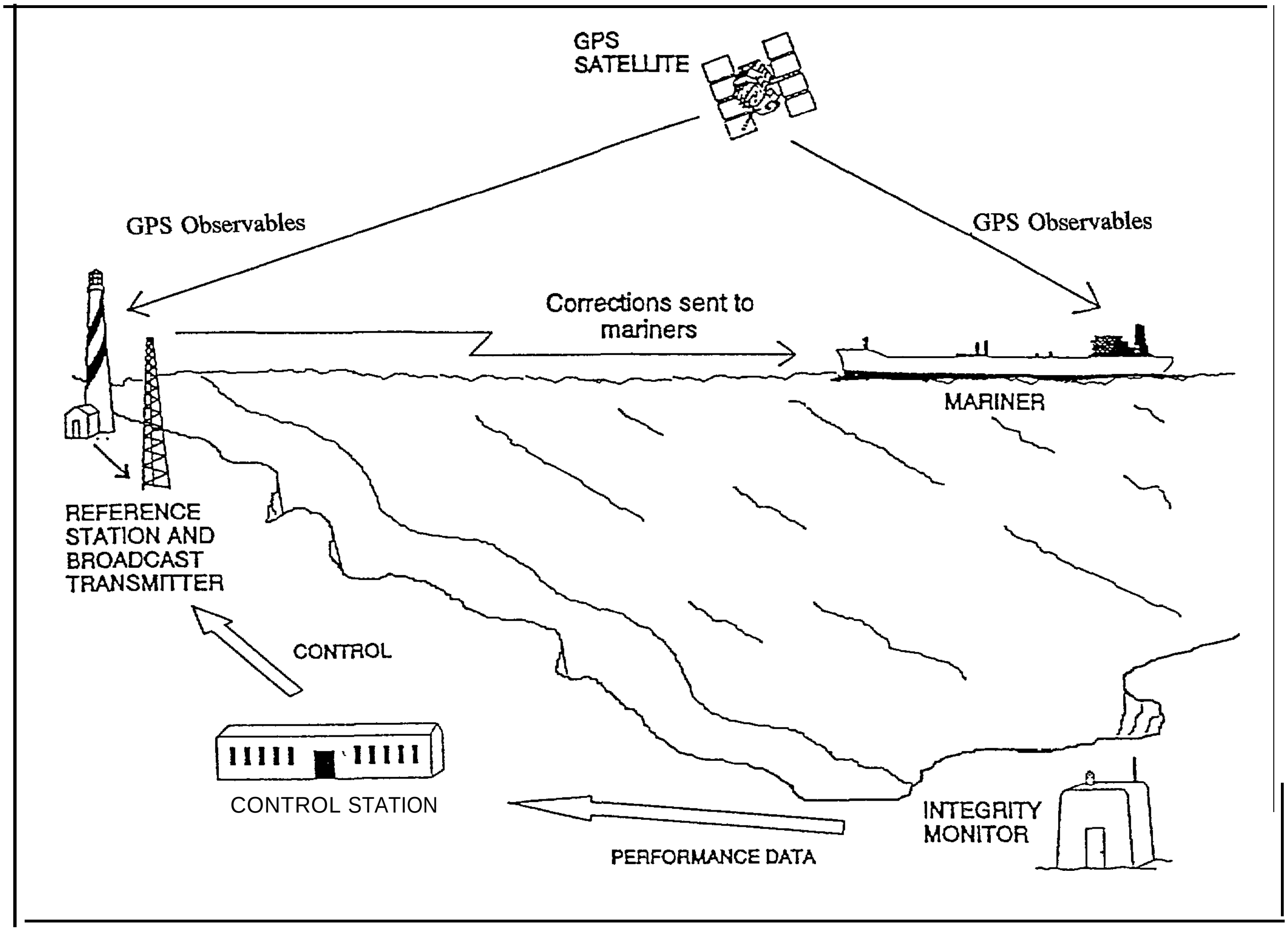


Figure A-2. USCG DGPS System Concept

A. Signal Characteristics

Maritime radiobeacons are being modified to accept MSK modulation. Real-time differential GPS corrections are input in the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) format and broadcast to all users capable of receiving the signals. The USCG does not plan to use data encryption. Radiobeacons were chosen because of existing infrastructure, compatibility with the useful range of DGPS corrections, international radio conventions, international acceptance, commercial availability of equipment, and highly successful field tests.

The data rate of DGPS transmissions will be 100 bps and 200 bps in selected waterways with more stringent VTS requirements. Prior to full implementation of DGPS, a decision may be made to use a 200 bps data rate at all DGPS broadcast sites.

The USCG's DGPS system will broadcast corrections to the user in the RTCM SC-104 format. The RTCM has defined data messages and an interface between the DGPS receiver and the data link receiver. The USCG DGPS Broadcast Standard (Commandant Instruction M16577.1) should be consulted for detailed information on the DGPS broadcasts. A description of some of the message types is contained below:

- **Type 1 Differential GPS Corrections.** This message contains the pseudorange corrections (PRC) and range-rate corrections (RRC) for all satellites in view of the reference station. When the USCG's DGPS service is fully implemented, the use of Type 1 message will be replaced by the Type 9 message.

- **Type 2 Delta Differential GPS Corrections.** Type 2 messages will not be used by the USCG DGPS Service. Continuous tracking receivers make the need for Type 2 messages obsolete and use of the message would only increase the latency of the broadcast. For each new issue of data (IOD) , there will be a 90 second delay before the broadcast of pseudorange corrections are computed with the new IOD.

- **Type 3 Reference Station Parameters.** The NAD 83 coordinates of the reference station with a resolution of 0.01 meter are found here. This message will nominally be broadcast twice per hour. User derived atmospheric corrections may be added through use of this message type.

- **Type 6 Null Frame.** This message is used to maintain data link synchronization in the event there are no other RTCM messages to transmit. In the operational GPS scenario, transmission of this message will be rare indeed.

- **Type 7 Radiobeacon Almanac.** This message provides location, frequency, service range and health information for adjacent broadcast transmitters as well as for the radiobeacon from which the message is broadcast. It can be used to acquire the next transmitter when in transit down the coast. This message will nominally be sent every 10 minutes.

- **Type High Rate Differential GPS Corrections.** Due to the advantages of greater impulse noise immunity, lower latency, less susceptibility to SA on one or more satellites, and a more timely alarm capability, the Type 9 message has been selected over the Type 1 message. Recent tests have demonstrated the substantial advantage gained through this use of the Type 9 message. PRC and RRC are broadcast for up to nine satellites which are above a 7.5 degree mask angle. The message indicates the nominal time (shown below as t_o) for which this data was valid. The user computes the current differential correction as follows:

$$PRC(t) = PRC(t_o) + RRC \cdot (t-t_o),$$

  where $PRC(t_o)$ is the PRC value in the PRC message. The user then applies the PRC by adding it to their pseudorange measurement. The RRC is included in an attempt to extend the life of the PRC, as the RRC is a "rate" term which is used to propagate PRCs in time. The Type 9 messages will contain the corrections for up to three satellites for each message. Also, unlike the Type 1 message, Type 9 messages can be used in accordance with the RTCM and IALA standards. The information contained before the first word with an uncorrectable error can be used.

- **Type 15 Atmospheric Parameters.** (To be developed.) The USCG plans to work with the National Geodetic Survey and the U.S. Army Corps of Engineers in developing this message to extend the high level of accuracy provided by the Reference Station further out into the coverage area. The use of a dual frequency Reference Station to generate this message will be explored - this particular message will most likely be of use-only to the dual frequency user.

- **Type 16 Special Message.** This is an ASCII message up to 90 characters long. It can be sent by service providers to broadcast warning information, such as scheduled outages. User equipment should have the ability to display this information to the navigator, with audible warning of receipt.

B. Accuracy

The accuracy of the USCG' s DGPS service is expected to be better than 10 meters (2 drms) in all approaches to major U.S. harbors. Prototype operations are now achieving accuracies on the order of 1 meter.

C. Availability

Availability will be 99.9 percent in selected waterways with more stringent VTS requirements and at least 99.7 percent in other parts of the coverage area.

D. Coverage

Figure A-3 shows the expected coverage of the USCG's maritime DGPS system.

E. Reliability

The number of outages per site will be less than 500 in one million hours of operation with a time to alarm of less than five seconds.

F. Fix Rate

The DGPS reference station computes corrections at least once per second. Due to the transmission time, users will receive updated corrections on an average of every five seconds for beacons transmitting at 100 bps and every 2.5 seconds for beacons transmitting at 200 bps.

G. Fix Dimensions

Maritime differential GPS provides three-dimensional positioning and velocity fixes.

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

DGPS system integrity is provided through an on-site integrity monitor and 24-hour operations at a DGPS control center. Users will be notified of an out-of-tolerance condition within five seconds.

In addition to providing a highly accurate navigational signal, DGPS also provides a continuous integrity check on satellite health. System integrity is a real concern with GPS. With the design of the ground segment of GPS, a satellite can be transmitting an unhealthy signal for 2 to 6 hours before it can be detected and corrected by the

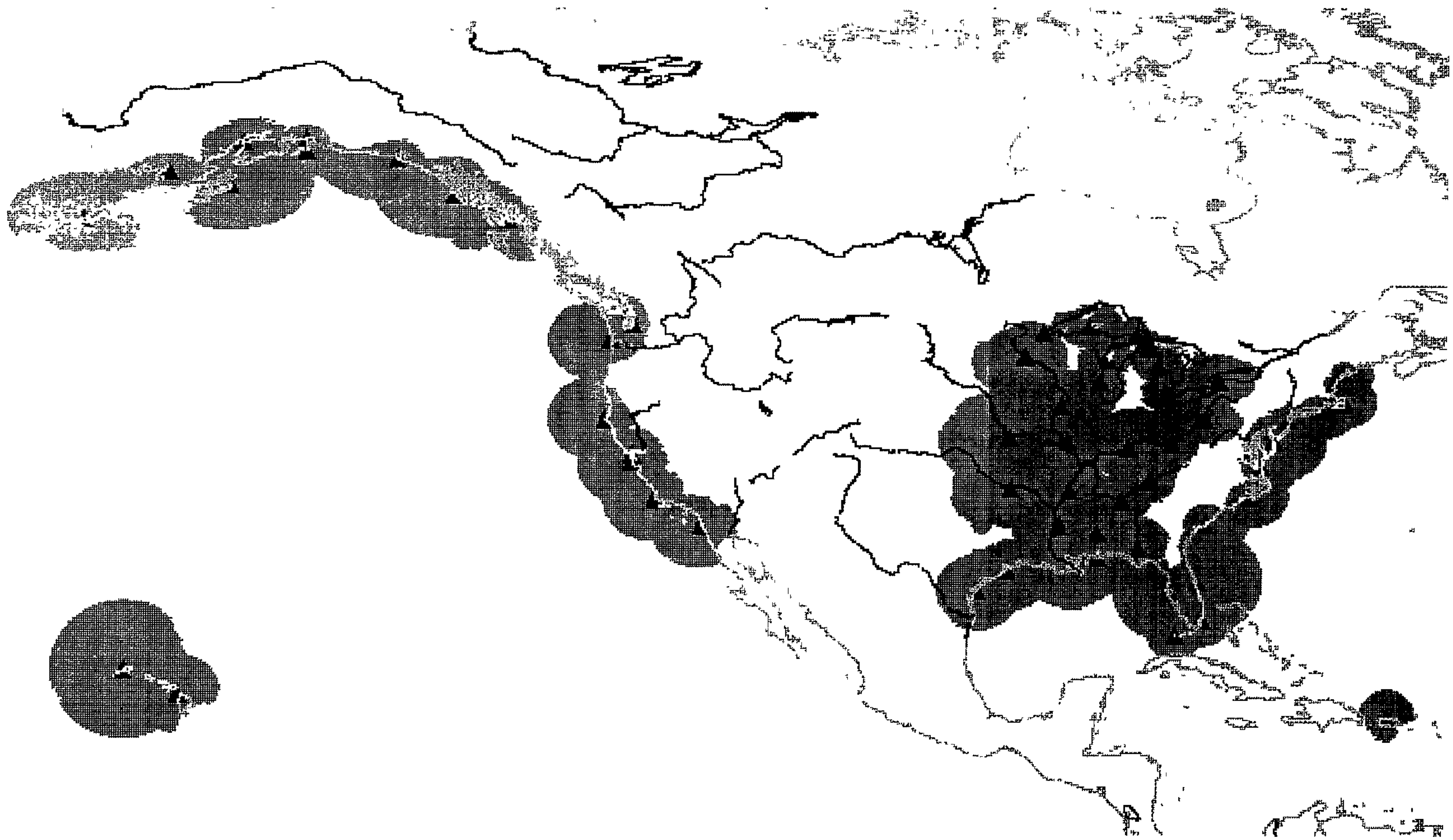


Figure A-3. Proposed Conus, Alaska and Hawaii Maritime DGPS Coverage

Master Control Station or before users can be warned not to use the signal. But with the continuous, real-time messages generated by DGPS, unhealthy satellites can still be used, or the navigator's receiver is directed not to use a particular satellite. This can eliminate the danger of the navigator relying on an erroneous signal.

A.2.10.2 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS will be a safety-critical system consisting of the equipment and software which augments the DOD-provided GPS Standard Positioning Service (see Figure A-4). It will provide a signal in space to WAAS users with the specific goal of supporting aviation navigation for the en route through Category I precision approach phases of flight. The signal in space will provide three services: (1) integrity data on GPS and GE0 satellites, (2) wide area differential corrections for GPS satellites, and (3) an additional ranging capability.

Figure A-4. WAAS Architecture

The GPS satellites' data is to be received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). These data are forwarded to data processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GE0 satellite navigation parameters. This information is to be sent to a Ground Earth Station (GES) and uplinked along with the GE0 navigation message to GE0 satellites. These GE0 satellites will then downlink this data on the GPS Link I (LI) frequency with a modulation similar to that used by GPS.

In addition to providing GPS integrity, the WAAS will verify its own integrity and take any necessary action to ensure that the system meets the WAAS performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA Airway Facilities NAS personnel.

The WAAS user receiver will process: (1) the integrity data to ensure that the satellites being used are providing in-tolerance navigation data, (2) the differential correction and ionospheric information data to improve the accuracy of the user's position solution, and (3) the ranging data from one or more of the GE0 satellites for position determination. The WAAS user receivers are not considered part of the WAAS.

A. Signal Characteristics

The WAAS will collect raw GPS obervable data through the GPS LI-C/A pseudorange data, the GPS LI/Link 2 (L2) code differential data (without knowledge of the Y-code), and the satellite navigation data from all GPS satellites that support the navigation service.

WAAS ground equipment will develop messages on ranging signals and signal quality parameters of the GPS and GE0 satellites. GE0 satellites will broadcast the WAAS messages to the users and provide ranging sources. The signals broadcast via the WAAS GEOs to the WAAS users are designed to require minimal standard GPS receiver hardware modifications. The GPS frequency and GPS-type modulation, including a C/A PRN code, will be used. In addition, the code phase timing will be synchronized to GPS time to provide a ranging capability.

B. Accuracy

Accuracies for the WAAS are currently based on aviation requirements. For the en route through nonprecision approach phases of flight, a horizontal accuracy of 100 meters 95 percent of the time is guaranteed with the requisite availability and integrity levels to support operations in the NAS. For the Category I precision approach phase of flight, horizontal and vertical accuracies are guaranteed at 7.6 meters 95 percent of the time.

C. Availability

The WAAS availability for the en route through nonprecision approach phases of flight is at least 0.99999. For the precision approach phase of flight, the availability is at least 0.999.

D. Coverage

The WAAS full service volume is defined from the surface up to 100,000 feet for the airspace of the 48 contiguous states, Hawaii, Puerto Rico, and Alaska (except for the Alaskan peninsula west of longitude 160 degrees West or outside of the GE0 satellite broadcast area).

E. Reliability

The WAAS will provide sufficient reliability and redundancy to meet the overall NAS requirements with no single point of failure. The overall reliability of the WAAS will approach 100 percent.

F. Fix Rate

This system provides a virtually continuous position update.

G. Fix Dimensions

The WAAS provides three-dimensional position fixing and highly-accurate timing information.

H. System Capacity

The user capacity is unlimited.

I. Ambiguity

The system provides no ambiguity of position fixing information.

J. Integrity

Integrity augmentation of the GPS SPS by the WAAS is a required capability that is both an operational characteristic and a technical characteristic. The required system performance levels for the integrity augmentation are the levels necessary so that GPS/WAAS can be used for all phases of flight.

Integrity for the WAAS is specified by three parameters: probability of hazardously misleading information (PHMI), time to alarm, and the alarm limit. For the en route through nonprecision approach phases of flight, the performance values are:

PHMI	10^{-7} per hour
Time to Alarm	8 seconds
Alarm Limit	Protection limits specified for each phase of flight

For the precision approach phase of flight, integrity performance values are:

PHMI	4×10^{-8} per approach
Time to Alarm	5.2 seconds
Alarm Limit	As required to remain within the category I tunnel

A.2.11 VTS

For information on VTS system characteristics, please contact the U.S. Coast Guard (G-NVT).

A.3 GPS Information Center (GPSIC)/Navigation Information Service

The U.S. Coast Guard's GPS Information Center (GPSIC), now called the Navigation Information Service, is the operational entity of the Civil GPS Service (CGS) which provides GPS status information to civil users of GPS. Its input is based on data from the GPS Control Segment, Department of Defense, and other sources. The mission of the GPSIC is to gather, process and disseminate timely GPS status information to civil users of GPS. Specifically, the functions performed by the Navigation Information Service include the following:

- Provide the Operational Advisory Broadcast (OAB) Service.
- Answer questions by telephone or written correspondence.
- Provide information to the public on the GPSIC services available.
- Provide instruction on the access and use of the information services available.
- Maintain tutorial, instructional, and other relevant handbooks and material for distribution to users.
- Maintain records of GPS broadcast information, GPS databases or relevant data for reference purposes.
- Maintain bibliography of GPS publications.

- Maintain and augment the computer and communications equipment as required.

- Develop new user services as required.

The GPSIC is transitioning to a Navigation Information Service and provides information on the status of the USCG operated radionavigation services such as Loran-C, Omega, and the developing DGPS service as well as other navigation information.

Information on GPS and USCG-operated radionavigation systems can be obtained from the USCG's Navigation Center (NAVCEN), 7327 Telegraph Road, Alexandria, VA 223 15-3998 by mail, or by telephone (703-3 13-5900) or fax (703-3 13-5920).

Table A-l 1 and Figure A-5 show the services through which the GPSIC provides Operational Advisory Broadcasts.

A.4 Intelligent Transportation Systems

The Intelligent Transportation Systems (ITS) program applies advanced and emerging technologies to surface transportation needs. Successful deployment of ITS services and systems will achieve improvements in safety, mobility and productivity, and reduce harmful environmental impacts, particularly those caused by traffic congestion. The ITS program has evolved from six major system areas, Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO), Advanced Vehicle Control Systems (AVCS), Advanced Public Transportation Systems (APTS), and Advanced Rural Transportation Systems (ARTS) into twenty eight inter-related user services which have been defined to date as part of the national program planning process. The basic components of the ITS are shown in Figure A-6. User services are defined, not along lines of common technologies, but based upon the services or benefits that various users might receive. The services are in various stages of maturity; some are available today, but others will require significant research, development, testing, and advances in technology applications before they are ready for deployment. The user services have been grouped into "bundles," based on likely deployment scenarios. The following is a description of the user services.

Travel and Traffic Management

- **Pre-Trip Travel Information:** Travelers access a complete range of intermodal transportation information at home, work, and other major sites where trips originate. For example, timely information on transit routes, schedules, transfers and fares, and ride matching services are included. Real-time information on accidents, road construction, alternate routes, traffic speeds along given routes, parking conditions,

Table A- 11. GPSIC Services

Service	Availability	Information Type	Contact Number
GPSIC Watchstander	24 hours	User Inquiries	(703) 313-5900 FAX (703) 313-5920
GPSIC Computer Bulletin Board Service	24 hours	Status Forecasts/Historic Outages NGS Data Omega/FRP Misc Information	(703) 313-5910 300-14,400 bps Sprintnet (X.25) 311020201328
GPSIC Voice Tape Recording	24 hours	Status Forecasts Historic	(703) 313-5907
WWV	Minutes 14 & 15	Status Forecasts	2.5,5, 10,15 and 20 MHz
WWVH	Minutes 43 & 44	Status Forecasts	2.5, 5, 10, and 15 MHz
USCG MIB	When Broadcasted	Status Forecasts	VHF Radio, Marine Band
DMA Broadcast Warnings	When Broadcasted	Status Forecasts Outages	
DMA Weekly Notice to Mariners	Published & Mailed Weekly	Status Forecasts Outages	(301) 227-3126
DMA NAVINFONET Automated Notice to Mariners System	24 hours	Status Forecasts Historic Almanacs For More Information Call	(301) 227-3351 300 Baud (301) 227-5925 1200 Baud (301) 277-4360 2400 Baud (301) 227-3296
NAVTEX Data Broadcast	When broadcasted 4 - 6 time/day	Status Forecasts Outages	518 kHz

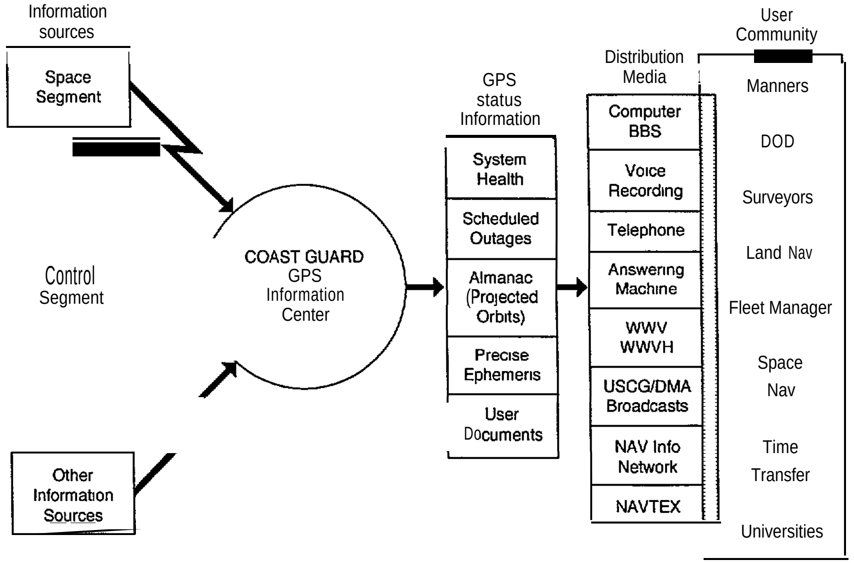


Figure A-5. GPSIC Information Flow

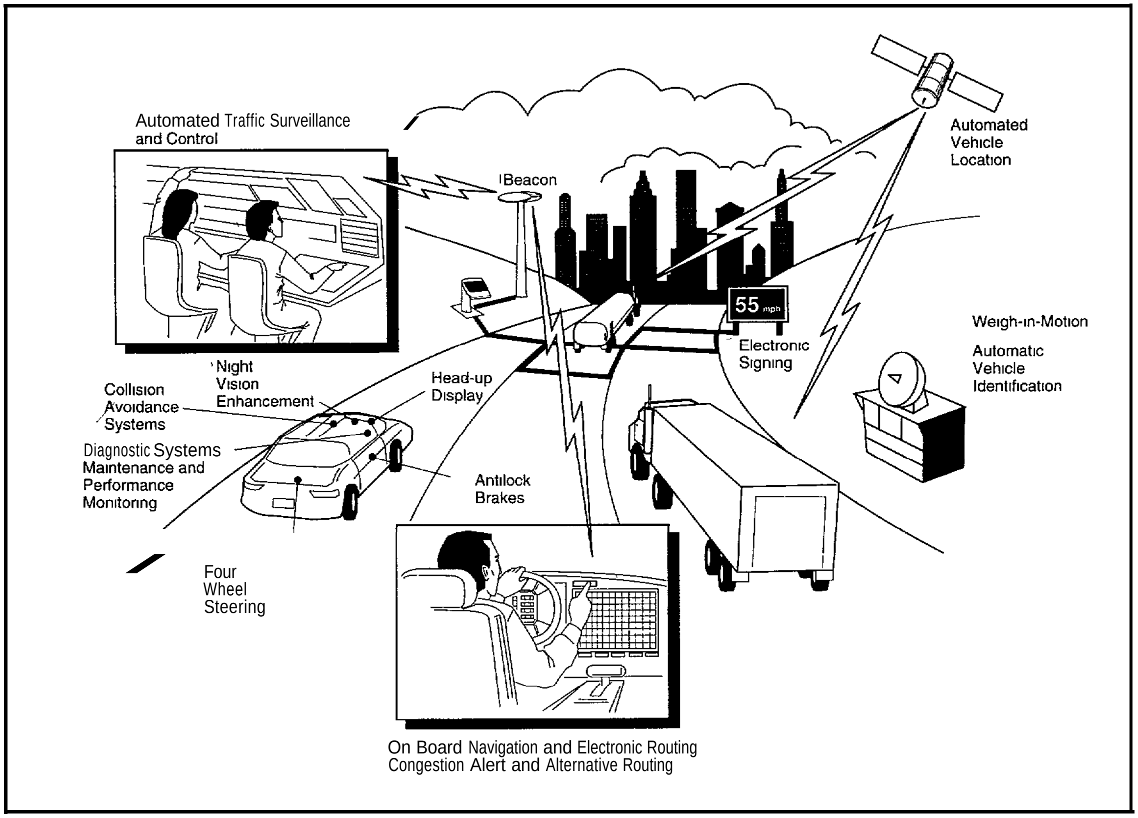


Figure A-6. Basic Components of Intelligent Transportation Systems

event schedules, and weather information complete the service. Based on this information, the traveler can select the best departure time, route and modes of travel, or decide to postpone or not to make the trip at all. Reducing congestion and improving mobility benefits all potential travelers.

- **En Route Driver Information:** Driver advisories are similar to pre-trip planning information, but are provided once travel begins. Driver advisories convey information about traffic conditions, incidents, construction, transit schedules, and weather conditions to drivers of personal, commercial and public transit vehicles. This information allows a driver to select the best route, or shift to another mode mid-trip if desired.

  In-vehicle signing, the second component of en-route driver information, would provide the same types of information found on physical road signs today, directly in the vehicle. The service could be extended to include warnings of road conditions and safe speeds for specific types of vehicles (e.g., autos, buses, large trucks), but potential users include drivers of all types of vehicles. This service might be especially useful to elderly drivers, or in rural areas with large numbers of tourists and unusual or hazardous roadway conditions.

- **Traveler Services Information:** Provides quick access to travel related services and facilities. Examples of information that might be included are the location, operating hours, and availability of food, parking, auto repair, hospitals, and police facilities. Traveler services information would be accessible in the home, office or other public locations to help plan trips, and might also be available en route. When fully deployed, this service will connect users and providers interactively, to request and provide needed information. A comprehensive, integrated service could support financial transactions like automatic billing for purchases.

- **Route Guidance:** Provides a suggested route to reach a specified destination. Early route guidance systems will be based on static information about the roadway network, transit schedules, etc. When fully deployed, route guidance systems will provide travelers with directions to their destinations based on real-time information about the transportation system. The route guidance service will consider traffic conditions, status and schedules of transit systems, and road closures in developing the best route. Directions will generally consist of simple instructions on turns or other upcoming maneuvers. Users of the service include not only drivers of all types of vehicles, but also non-vehicular travelers, such as pedestrians or bicyclists, who could get specialized route guidance from a hand-held device.

- **Ride Matching and Reservation:** Provides real-time ride matching information and reservations to users in their homes, offices or other locations, and assists transportation providers with vehicle assignments and scheduling. The service will also provide a clearinghouse for financial transactions. This will expand the market for ridesharing as an alternative to single occupant automobile travel, and will provide for enhanced alternatives for special population groups, such as the elderly or the handicapped. Convenient ride sharing is especially important to commuters.

- **Incident Management:** Enhances existing capabilities for detecting incidents and taking the appropriate actions in response to them. The service will help officials to quickly and accurately identify a variety of incidents, and to implement a response which minimizes the effects of these incidents on the movement of people and goods. Traffic movement adjustments over a wide area would be executed through the Traffic Control user service, while decisions at the site of the incident will be made by police agencies. In addition, the service will help officials to predict traffic or highway conditions so that they can take action in advance to prevent potential incidents or minimize their impacts. While the users of this service are primarily public officials, commercial and transit operators and the traveling public all benefit from improved incident management capabilities.

- **Travel Demand Management:** Generates and communicates management and control strategies that support the implementation of programs to (1) reduce the number of individuals who choose to drive alone, especially to work, (2) increase the use of high occupancy vehicles and transit, (3) reduce the impacts of high polluting vehicles, and (4) provide a variety of mobility options for those who wish to travel in a more efficient manner, for example in non-peak periods. The service allows employers to better accommodate the needs and lifestyles of employees by encouraging alternative work arrangements such as variable work hours, compressed work weeks, and telecommuting. Travel demand management strategies could ultimately be applied dynamically, when congestion or pollution conditions warrant. For example, disincentives such as increased tolls and parking fees could be applied during pollution alerts or when major incidents occur, while transit fares would be lowered to accommodate the increased number of travelers changing modes from driving alone. Such strategies will reduce the negative impacts of traffic congestion on the environment and overall quality of life.

- **Traffic Control:** Integrates and adaptively controls the freeway and surface street systems to improve the flow of traffic, give preference to transit and other high occupancy vehicles, and minimize congestion while maximizing the movement of people and goods. Through appropriate traffic controls, the service will also promote the safety of non-vehicular traveler, such as pedestrians and bicyclists. This service gathers data from the transportation system, fuses it into usable information, and uses it to determine the optimum assignment of right-of-way to vehicles and pedestrians. The real-time traffic information collected by the Traffic Control service also provides the foundation for many other user services.

  While the actual users of the service will generally be public transportation officials, drivers of all types of vehicles, transit riders, pedestrians, bicyclists, and other travelers benefit from improved traffic flow.

Public Transportation Management

- **En Route Transit Information:** Provides the same type of information as pre-trip planning services, once public transportation travel begins. Real-time, accurate transit service information on board the vehicle helps travelers make effective transfer decisions and itinerary modifications as needed while a trip is underway.

- **Public Transportation Management:** Computer analysis of real-time vehicle and facility status will improve operations and maintenance. The analysis identifies deviations from schedule and provides potential solutions to dispatchers and drivers. Integrating this capability with the Traffic Control Service can help maintain transportation schedules and assure transfer connections in inter-modal transportation. Information regarding passenger loading, bus running times, and mileage accumulated will help improve service and facilitate administrative reporting. Automatically recording and verifying performed tasks will enhance transit personnel management. Improved efficiency benefits transit providers and customers alike.

- **Personalized Public Transit:** Small publicly or privately operated vehicles operate on-demand assignments to pick up passengers who have requested service and deliver them to their destinations. Route deviation schemes, where vehicles would leave a fixed route for a short distance to pick up or discharge passengers, is another way of improving service under certain conditions. These transit vehicles can consist of small buses, taxicabs, or other small shared ride vehicles. They can essentially provide “door-to-door” service, expanding a route’s coverage in less populated locations and neighborhoods. This service can potentially provide transportation at lower cost and with greater convenience than conventional fixed route transit.

- **Public Travel Security:** Systems monitor the environment in transit stations, parking lots, bus stops, and transit vehicles and generate alarms either automatically or manually as necessary. This improves security for both transit riders and operators. Transportation agencies and authorities can integrate this user service with other anti-crime plans.

Electronic Payment

- **Electronic Payment Services:** Will foster intermodal travel by providing a common electronic payment medium for all transportation modes and functions, including tolls, transit fares, and parking. A common service fee and payment structure, employing multi-use “smart cards,” could integrate all modes of transportation including roadway pricing options. The flexibility electronic payment services offer will have an impact on travel demand management. In particular, they will enable relatively easy application of road pricing policies and could significantly influence departure times and mode selection. Electronic payment's primary benefit is convenience for all travelers and transportation providers.

Commercial Vehicle Operations

- **Commercial Vehicle Electronic Clearance:** This service will enable transponder-equipped trucks and buses to have their safety status, credentials, and weight checked at mainline speeds. Vehicles that are safe and legal and have no outstanding out-of-service citations will be allowed to pass the inspection/weight facility without delay.

  By working with Mexico and Canada, a more efficient traffic flow would be provided at border crossings and the deployment of technologies in these countries could ultimately prevent overweight, unsafe, or improperly registered vehicles from entering the United States. Truckers, shippers, and regulators will all benefit from improved productivity.

- **Automated Roadside Safety Inspection:** Automated roadside inspections would allow "real-time" access at the roadside to the safety performance record of carriers, vehicles, and drivers. Such access will help determine which vehicle or driver should be stopped for an inspection, as well as ensuring timely correction of previously identified problems.

  It would, for example, allow for more rapid and accurate inspection of brake performance at the roadside. Through the use of sensors and diagnostics, it would efficiently check vehicle systems and driver requirements and ultimately driver alertness and fitness for duty. Improved safety benefits truckers, shippers and regulators.

- **Commercial Vehicle Administrative Processes:** Electronically purchasing credentials would provide the carrier with the capability to electronically purchase annual and temporary credentials via computer link. It will reduce burdensome paperwork and processing time for both the states and the motor carriers.

  For automated mileage and fuel reporting and auditing, this service would enable participating interstate carriers to electronically capture mileage, fuel purchased, trip, and vehicle data by state. It would also automatically determine mileage traveled and fuel purchased in each state, for use by the carrier in preparing fuel tax and registration reports to the states. Currently, the administrative burden on carriers to collect and report mileage and fuel purchased within each state is significant. This service would significantly reduce the cost for collecting both types of data.

- **Onboard Safety Monitoring:** Onboard systems would monitor the safety status of a vehicle, cargo, and driver at mainline speeds. Vehicle monitoring would include sensing and collecting data on the condition of critical vehicle components such as brakes, tires, and lights, and determining thresholds for warnings and countermeasures. Cargo monitoring would involve sensing unsafe conditions relating to vehicle cargo, such as shifts in cargo while the vehicle is in operation. Driver monitoring is envisioned to include the monitoring of driving time and alertness using non-intrusive technology and the development of warning systems for the driver, the carrier, and the enforcement official. A warning of unsafe condition would first be provided to the driver, then to the carrier and roadside enforcement officials and would possibly prevent an accident before it happens. This service would minimize driver and equipment-related accidents for participating carriers.

- **Commercial Fleet Management:** The availability of real-time traffic information and vehicle location for commercial vehicles would help dispatchers to better manage fleet operations by helping their drivers to avoid congested areas and would also improve the reliability and efficiency of carriers' pickup-and-delivery operations. The benefits from this service would be substantial for those intermodal and time-sensitive fleets that can use these Intelligent Vehicle Highway System technologies to make their operations more efficient and reliable.

- **Hazardous Materials and Incident Notification:** Enhances the safety of shipments of hazardous materials by providing enforcement and response teams with timely, accurate information on cargo contents to enable them to react properly in emergency situations. The system would focus on determining when an incident involving a truck carrying hazardous material occurs, the nature and location of the incident, and the material or combination of materials involved so that the incident can be handled properly.

Emergency Management

- **Emergency Vehicle Management:** This user service includes three capabilities: fleet management, route guidance, and signal priority.

Fleet management will improve the display of emergency vehicle locations and help dispatchers efficiently task the units that can most quickly reach an incident site. Route guidance directs emergency vehicles to an incident location. Signal priority clears traffic signals in an emergency vehicle's route. Primary users include police, fire, and medical units.

- **Emergency Notification and Personal Security:** This service includes two capabilities: driver and personal security and automatic collision notification. Driver and personal security capabilities provide for user initiated distress signals for incidents such as mechanical breakdowns and carjackings. Automatic collision notification identifies a collision and automatically sends information regarding location, nature, and severity to emergency personnel.

Advanced Vehicle Safety Systems

- **Longitudinal Collision Avoidance:** Helps reduce the number and severity of collisions. It includes the sensing of potential or impending collisions, prompting a driver's avoidance actions, and temporarily controlling the vehicle.

- **Lateral Collision Avoidance:** Provides crash warnings and controls for lane changes and road departures. It will help reduce the number of lateral collisions involving two or more vehicles, or crashes involving a single vehicle leaving the roadway.

  For lane changes, a situation display can continuously monitor the vehicle's blind spot and drivers can be actively warned of an impending collision. If needed, automatic control can effectively respond to situations very rapidly. Warning systems can also alert a driver to an impending road departure, provide help in keeping the vehicle in the lane, and ultimately provide automatic control of steering and throttle in dangerous situations.

- **Intersection Collision Avoidance:** Warns drivers of imminent collisions when approaching or crossing an intersection that has traffic control (e.g., stop signs or traffic signals). This service also alerts the driver when the right-of-way at the intersection is unclear or ambiguous.

- **Vision Enhancement for Crash Avoidance:** Improved visibility would allow the driver to avoid potential collisions with other vehicles or obstacles in the roadway, as well as help the driver comply with traffic signs and signals. This service requires in-vehicle equipment for sensing potential hazard, processing this information, and displaying it in a way that is useful to a driver.

- **Safety Readiness:** In-vehicle equipment could unobtrusively gauge a driver's condition and provide a warning if he or she is drowsy or otherwise impaired. This service could also internally monitor critical components of an auto beyond the standard oil pressure and engine temperature lights. Equipment within the vehicle could also detect unsafe road conditions, such as bridge icing and standing water on a roadway, and provide a warning to the driver.

- **Pre-Crash Restraint Deployment:** Identifies the velocity, mass, and direction of the vehicles and objects involved in a potential crash and the number, location, and major physical characteristics of any occupants. Responses include tightening lap-shoulder belts, arming and deploying air bags at an optimal pressure, and deploying roll bars.

- **Automated Vehicle Operation:** Automated vehicle operations are a long term goal of Intelligent Transportation Systems which would provide vast improvements in safety by creating a nearly accident free driving environment. Drivers could buy vehicles with the necessary instrumentation or retrofit an existing vehicle. Vehicles that are incapable of automated operation during some transition period, will drive in lanes without automation.

These 28 user services have evolved from six major system areas:

- **Advanced Traffic Management Systems (ATMS):** Permit real-time adjustment of traffic control systems and variable signing for driver advice. Applications in selected corridors have reduced delay, travel time, and accident incidence. ATMS uses coordinated signaling systems, video surveillance of corridors, ramp metering, automated toll collection, and variable message signs (VMS).

- **Advanced Traveler Information Systems (ATIS):** Deal with the acquisition, analysis, communication, presentation, and use of information to assist the surface transportation traveler in moving from origin to destination in the way which best satisfies the traveler's needs for safety, efficiency, and comfort. Travel may involve a single mode or linked, multiple modes. These systems will let travelers know their locations and how to find services, and will permit communication between travelers and ATMS for continuous advice on traffic conditions and alternate routes. In addition, ATIS provides the driver with warnings related to road safety.

- **Commercial Vehicle Operations (CVO):** Expedite deliveries, improve operational efficiency, improve incident response, and increase safety. CVO makes use of ATIS features critical to commercial and emergency vehicles. A primary goal of CVO is to reduce regulatory burdens and inefficiency. Many of the technologies related to CVO are already available in the marketplace. Automatic Vehicle Identification (AVI) devices are used in several locations to allow the electronic transfer of funds so travelers can pay tolls without stopping. GPS and Loran-C technologies can be used to track the location of individual vehicles for fleet management. Weigh-in-Motion (WIM), combined with Automatic Vehicle Classification (AVC), sorts vehicles for weight inspections. Onboard computers are available to monitor track performance.

- **Advanced Vehicle Control Systems (AVCS):** Enhance the control of vehicles by facilitating and augmenting driver performance and, ultimately, relieving the driver of most tasks on designated, instrumented roadways. AVCS includes vehicle- and/or roadway-based electromechanical and communications devices.

- **Advanced Public Transportation Systems (APTS):** Work in conjunction with ATMS and ATIS to provide mass transportation users and operators (e.g., buses, Vanpools, high-occupancy vehicle (HOV) lanes, carpools, taxi cabs) with up-to-date information on status, schedules, and availability of public transit systems. Automatic vehicle location and monitoring systems will provide information to improve fleet management and inform riders of their connections. Electronic fare media will reduce the inconvenience of cash handling, provide new marketing data, and integrate third party billing for transit services. New HOV priority schemes using Intelligent Transportation Systems technologies will be devised and monitored automatically to enforce HOV facility use. Other examples of diverse transit applications are fixed routine transit, demand responsive transit, transit mobile supervisors, and passenger/consumer information.

- **Advanced Rural Transportation Systems (ARTS):** Would include navigation aids, accident and incident response, information on dangerous road conditions, environmental conditions, farming activities, road maintenance, and railroad crossing information.

Appendix B

Reference Systems

B.1 Chart Reference Systems

Geodetic datums are reference coordinate systems used to establish the precise geographic position and elevation of features on the surface of the Earth. They are established at all levels of government (international, national, and local) and form the legal basis for all positioning and navigation. Within the last 2 to 3 decades, there have been great advances in our knowledge of the shape and size of the Earth (i.e., geodetic knowledge). Geodesy and navigation are to a large extent based on Earth Centered Body Fixed (ECBF) coordinate systems. These are Cartesian coordinate systems with origins at the center of mass of the Earth. The old datums have generally been based on localized surface monuments (and associated agreements) and were defined by a reference ellipsoid that was not Earth centered.

The Department of Defense (DOD) Global Positioning System (GPS) uses the World Geodetic System of 1984 (WGS 84) as its coordinate frame. WGS 84 is an ECBF coordinate system upon which all U.S. military and much civilian navigation will be based. Within the U.S., the National Geodetic Survey (NGS) is the primary civilian legal authority for the establishment of U.S. datums. Until recently, the horizontal datum used throughout most of the U.S. and Canada was the North American Datum of 1927. NAD 27 was not Earth centered. Until recently, nearly all nautical charts, aeronautical charts, Federal surveys, and associated data provided by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) were legally established with respect to NAD 27. In 1986, NGS completed a new horizontal datum known as the North American Datum of 1983 (NAD 83). NAD 83 is now the legal datum for surveying, mapping, and charting in the U.S. For purposes of navigation, mapping and charting, NAD 83 and WGS 84 are effectively equivalent (i.e., they differ by no more than a few meters from one another).

There is also a vertical (height) datum. Until recently, the legal vertical datum in the U.S. has been the National Geodetic Vertical Datum of 1929 (NGVD 29). In 1991, the NGS completed the North American Vertical Datum of 1988 (NAVD 88). NAVD 88 is now the legal vertical datum in the U.S. Vertical datum products and activities are being converted from NGVD 29 to NAVD 88. The conversion between GPS determined heights (ellipsoidal heights) and vertical datum (orthometric) heights is made by using a geoid model associated with the respective vertical datum. NGS has developed a geoid model, GEOID 93, to support such conversions.

B.2 Nautical Charts

Most nautical charts are based on regional horizontal datums which have been defined over the years independent of each other.

These include charts published by the Defense Mapping Agency (DMA) and NOS. In addition, in many parts of the world, the positional accuracy of chart features (such as hazards to navigation) sometimes varies from chart to chart and, in some cases, within a chart. Certain charts for waters in the southern hemisphere, for example, do not show islands in their correct geodetic positions, absolute or relative. Therefore, datums and limited chart accuracy must be considered when a navigational fix is plotted by a navigator on a nautical chart. Modern navigational positioning is based on satellite systems which are geocentric by definition, and these satellite coordinate systems differ significantly in many cases with the local or regional datums currently used for nautical charts. In addition to this difference, the plotted detail, such as soundings and navigational aids, contain a minimal plottable error that ranges between 0.5 mm and 1 .O mm on paper.

Virtually all radionavigation equipment incorporating coordinate converters (automatic computation of geodetic latitude and longitude from data received from a radionavigation system) were, until recently, programmed with the World Geodetic System of 1972 (WGS 72). Today, new radionavigation equipment coordinates, especially from differential GPS systems, are computed based on WGS 84, or, equivalently, in the U.S., NAD 83.

The large majority of the nautical charts published by NOS have been compiled based on a regional datum: NAD 27. The remaining NOS nautical charts were published on eight other local or regional datums. As stated, NOS has now adopted a geocentric datum: NAD 83. NOS has begun the conversion of most of its nautical charts to NAD 83. The charts of the Pacific islands, published by NOS, will be compiled based on WGS 84. As stated before, for charting purposes, NAD 83 is equivalent to WGS 84. As charts are converted to NAD 83, datum transformation notes will be added which report the amount of shifts from NAD 27 coordinates for each chart. These shifts can be in excess of 100 m and care must be taken not to mix NAD 83 and NAD 27 values while navigating.

Improvements in worldwide navigation accuracy, which are occurring with the implementation of GPS, will be significant. However, the ability to navigate safely along the coastlines of the world and on the high seas will remain limited where accurate, up-to-date hydrography and associated topographic features are not all positioned on the same satellite-based reference system.

B.3 Aeronautical Charts

The ultimate responsibility for the accuracy of air cartographic positional data rests with NOS. Section 307(b)(3) of the Federal Aviation Act authorizes the FAA, subject to available appropriations, to arrange for the publication of aeronautical maps and charts necessary for the safe and efficient movement of aircraft in air navigation utilizing the facilities and assistance of other Federal agencies. NOS, in turn, provides many of these services. Within the National Airspace System (NAS), the NGS establishes the basic U.S. datum that legally controls all positioning within the U.S. The Nautical Charting Division (NCD) of NOS conducts the Airport Obstruction Clearance Surveys (OC Surveys) which establish the positioning of 750 U.S. major civil airports and all navigation aids to existing U.S. datums. The NGS has completed the Airport Datum Monument Program (ADAM) which establishes datum monuments on 1400 non-OC surveyed airports. The ADAM data, which include end-of-runway coordinates, were determined using GPS and are available in NAD 27 and NAD 83 datums. The FAA has converted aeronautical charts to NAD 83. NOS is currently undertaking a large re-observation program to obtain high-accuracy NAD 83 positions at U.S. airports.

The FAA conversion from NAD 27 to NAD 83 has a major impact on the FAA. All positional data currently used within the NAS requires conversion. The NGS has determined that the horizontal differences between NAD 27 and NAD 83 are as large as 450 m in Hawaii, 160 m in Alaska, and 100 m in the central U.S. The horizontal differences are not uniformly distributed. Vertical datum differences are relatively minor and the transformation will be performed after the horizontal datum conversion. GPS equipment derives position information referenced to WGS 84. Databases produced for use in the contiguous U.S., Alaska, and Hawaii contain coordinates referenced to NAD 83 and NAVD 88. For the purposes of aircraft navigation, coordinates referenced to NAD 83 and NAVD 88 correspond to the coordinates for the same locations referenced to WGS 84.

B.4 GPS and the Evolution of Charts and Datums

Historically, there has been a horizontal datum (e.g., NAD 27 and the original NAD 83) and a vertical (orthometric) datum (e.g., NGVD 29 and NAVD 88). GPS has provided the means to develop a three-dimensional datum. Once the NGS revisited NAD 83 monuments and made extensive high-accuracy measurements, NAD 83 became three dimensional. The three dimensions are geodetic latitude, longitude, and ellipsoid height. Ellipsoid height is the height above a specified Earth-centered ellipsoid. Orthometric height remains referenced to NAVD 88 and is based on spirit leveling and is traditionally thought of as the height above mean sea level. Orthometric height and ellipsoid height can differ by about 100 m, and thus there can be no room for confusion when landing an airplane!

By interagency agreements between NOAA and the USCG and the FAA, NGS will precisely measure the location of USCG Beacon sites and FAA Wide Area Augmentation System sites. These will be continuously operated reference sites (CORS). Besides the USCG and FAA sites there are others such as those operated by the U.S. Army Corps of Engineers (COE), NOAA, and other organizations. NGS will determine and monitor the geodetic positions of these CORS at the decimeter (or better) level.

Thus, for the first time, all radionavigation users will have the opportunity to reckon position precisely and based on the same geodetic datum. Whereas, up to the present time, nautical and aeronautical "paper" charts have provided no better than few meter resolution, the advances described above permit "paperless" or digital charts to have greater resolution and accuracy. For the first time, the systems upon which the chart is made and used will be the same.

B.5 Electronic Chart Display Information System (ECDIS)

The Electronic Chart Display Information System (ECDIS) has emerged as a promising navigation aid that will result in significant improvements to maritime safety and commerce. More than simply a graphics display, ECDIS is a real-time geographic information system (GIS) that combines both spatial and textual data into a readily useful operational tool. As an automated decision aid that is capable of continuously determining a vessel's position in relation to land, charted objects, aids to navigation, and unseen hazards, ECDIS represents an entirely new approach to maritime navigation and piloting. It is expected that ECDIS will eventually replace the need to carry paper charts.

The development of an international performance standard for ECDIS was finalized by the International Maritime Organization (IMO) in May 1994. The IMO Performance Standards for ECDIS is slated for formal adoption by the Nineteenth Assembly of IMO in September 1995. To ensure early dissemination, IMO issued ECDIS Performance Standards as MCS/Circ. 637 on May 27,1994.

As specified in the IMO Performance Standards, the primary function of ECDIS is to contribute to safe navigation. ECDIS must be capable of displaying all chart information necessary for safe and efficient navigation organized by, and distributed on the authority of, government-authorized hydrographic offices. With adequate backup arrangements, ECDIS may be accepted as complying with the up-to-date charts required by regulation V/20 of the Safety-of-Life-at-Sea (SOLAS) Convention of 1974. In operation, ECDIS should reduce the navigational workload compared to using the paper chart. It should enable the mariner to execute in a convenient and timely manner all route planning, route monitoring, and positioning currently performed on paper charts. ECDIS should also facilitate simple and reliable updating of the electronic navigational chart. Similar to the requirements for shipborne radio equipment forming a part of the global maritime distress and safety system (GMDSS), and for electronic navigational aids, ECDIS onboard a SOLAS vessel should be in compliance with the IMO Performance Standard.

For the electronic navigational positioning system to be used with an IMO-compliant ECDIS, it is specified that:

- The vessel's position be derived from a continuous positioning system of an accuracy consistent with the requirements of safe navigation.
- A second independent positioning method of a different type should be provided; and, ECDIS should be capable of detecting discrepancies between the primary and secondary positioning systems.
- ECDIS provide an indication when the input from a positioning system is lost or malfunctioning.

When ECDIS and radar/Automatic Radar Plotting Aid (ARPA) are superimposed on a single display, they provide a system that can be used both for navigation and collision avoidance. As specified in the IMO Performance Standards, radar information may be added to the ECDIS display, as long as it does not degrade the display and is clearly distinguishable from the electronic navigational chart. The IMO Performance Standard further stipulates that both the ECDIS and radar use a common reference system (e.g., GPS/DGPS), and that the chart and radar image match in scale and orientation.

Appendix C

Definitions

Accuracy - The degree of conformance between the estimated or measured position and/or velocity of a platform at a given time and its true position or velocity. Radionavigation system accuracy is usually presented as a statistical measure of system error and is specified as:

- Predictable - The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix B discusses chart reference systems and the risks inherent in using charts in conjunction with radionavigation systems.)

- Repeatable - The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.

- Relative - The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

Air Traffic Control (ATC) - A service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic.

Approach Reference Datum - A point at a specified height above the runway centerline and the threshold. The height of the MLS approach reference datum is 15 meters (50 ft). A tolerance of plus 3 meters (10 ft) is permitted.

Area Navigation (RNAV) - Application of the navigation process providing the capability to establish and maintain a flight path on any arbitrarily chosen course that remains within the coverage area of navigation sources being used.

ARISTOTELES - European/U.S. gravity mission planned for 1996.

Automatic Dependent Surveillance - A function in which aircraft automatically transmit navigation data derived from onboard navigation systems via a datalink for use by air traffic control.

Availability - The availability of a navigation system is the percentage of time that the services of the system are usable. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigational signals transmitted from external sources are available for use. Availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

Block II/IIA - The satellites that will form the initial GPS constellation at FOC.

Cellular Triangulation - A method of location determination using the cellular phone system where the control channel signals from a mobile phone are captured by two or more fixed base stations and processed according to an algorithm to determine the location of the mobile receiver.

Circular Error Probable (CEP) - In a circular normal distribution (the magnitudes of the two one-dimensional input errors are equal and the angle of cut is 90^{o}), circular error probable is the radius of the circle containing 50 percent of the individual measurements being made, or the radius of the circle inside of which there is a 50 percent probability of being located.

Coastal Confluence Zone (CCZ) - Harbor entrance to 50 nautical miles offshore or the edge of the continental shelf (100 fathom curve), whichever is greater.

Common-use Systems - Systems used by both civil and military sectors.

Conterminous U.S. - Forty-eight adjoining states and the District of Columbia.

Coordinate Conversion - The act of changing the coordinate values from one system to another; e.g., from geodetic coordinates (latitude and longitude) to Universal Transverse Mercator grid coordinates.

Coordinated Universal Time (UTC) - UTC, an atomic time scale, is the basis for civil time. It is occasionally adjusted by one-second increments to ensure that the difference between the uniform time scale, defined by atomic clocks, does not differ from the earth’s rotation by more than 0.9 seconds.

Coverage - The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the user to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

Differential - A technique used to improve radionavigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radionavigation system, operating in the same area.

Distance Root Mean Square (drms) - The root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. As used in this document, 2 drms is the radius of a circle that contains at least 95 percent of all possible fixes that can be obtained with a system at any one place. Actually, the percentage of fixes contained within 2 drms varies between approximately 95.5 percent and 98.2 percent, depending on the degree of ellipticity of the error distribution.

En Route - A phase of navigation covering operations between a point of departure and termination of a mission. For airborne missions the en route phase of navigation has two subcategories, en route domestic and en route oceanic.

En Route Domestic - The phase of flight between departure and arrival terminal phases, with departure and arrival points within the conterminous United States.

En Route Oceanic - The phase of flight between the departure and arrival terminal phases, with an extended flight path over an ocean.

Flight Technical Error (FTE) - The contribution of the pilot in using the presented information to control aircraft position.

Full Operational Capability (FOC) - For GPS, this is defined as the capability that will occur when 24 operational (Block II/IIA) satellites are operating in their assigned orbits and have been tested for military functionality and meet military requirements.

Geocentric - Relative to the Earth as a center, measured from the center of mass of the Earth.

Geodesy - The science related to the determination of the size and shape of the Earth (geoid) by such direct measurements as triangulation, leveling, and gravimetric observations; which determines the external gravitational field of the Earth and, to a limited degree, the internal structure.

Geometric Dilution Of Precision (GDOP) - All geometric factors that degrade the accuracy of position fixes derived from externally-referenced navigation systems.

Inclination - One of the orbital elements (parameters) that specifies the orientation of an orbit. Inclination is the angle between the orbital plane and a reference plane, the plane of the celestial equator for geocentric orbits and the ecliptic for heliocentric orbits.

Initial Operational Capability (IOC) - For GPS, this is defined as the capability that will occur when 24 GPS satellites (Block I/II/IIA) are operating in their assigned orbits and are available for navigation use.

Integrity - Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

Multipath Transmission - The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths. When two or more signals arrive simultaneously, wave interference results. The received signal fades if the wave interference is time varying or if one of the terminals is in motion.

Meaconing - A technique of manipulating radio frequency signals to provide false navigation information.

Nanosecond (ns) - One billionth of a second.

National Airspace System (NAS) - The NAS includes U.S. airspace; air navigation facilities, equipment and services; airports or landing areas; aeronautical charts, information and service; rules, regulations and procedures; technical information; and labor and material used to control and/or manage flight activities in airspace under the jurisdiction of the U.S. System components shared jointly with the military are included.

National Command Authority (NCA) - The NCA is the President or the Secretary of Defense, with the approval of the President. The term NCA is used to signify constitutional authority to direct the Armed Forces in their execution of military action. Both movement of troops and execution of military action must be directed by the NCA; by law, no one else in the chain of command has the authority to take such action.

Nautical Mile (nm) - A unit of distance used principally in navigation. The International Nautical Mile is 1,852 meters long.

Navigation - The process of planning, recording, and controlling the movement of a craft or vehicle from one place to another.

Nonprecision Approach - A standard instrument approach procedure in which no electronic glide slope is provided (e.g., VOR, TACAN, Loran-C, or NDB).

Primary Means of Navigation - Identifies navigation equipment which provides the only required means on an aircraft of satisfying the necessary level of accuracy, integrity, and availability for a particular area, route, procedure, or operation. The failure of a primary means of navigation requires reversion to a non-normal means of navigation (e.g., dead reckoning).

Precise Time - A time requirement accurate to within 10 milliseconds.

Precision Approach - A standard instrument approach procedure using a ground-based system in which an electronic glide slope is provided (e.g., ITS).

Radiodetermination - The determination of position, or the obtaining of information relating to positions, by means of the propagation properties of radio waves.

Radiolocation - Radiodetermination used for purposes other than those of radionavigation.

Radionavigation - The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

Receiver Autonomous Integrity Monitoring (RAIM) - A technique whereby a civil GPS receiver/processor determines the integrity of the GPS navigation signals without reference to sensors or non-DOD integrity systems other than the receiver itself. This determination is achieved by a consistency check among redundant pseudorange measurements.

Reliability - The probability of performing a specified function without failure under given conditions for a specified period of time.

Required Navigation Performance - A statement of the navigation performance accuracy necessary for operation within a defined airspace, including the operating parameters of the navigation systems used within that airspace.

RHO (Ranging Mode) - A mode of operation of a radionavigation system in which the times for the radio signals to travel from each transmitting station to the receiver are measured rather than their differences (as in the hyperbolic mode).

Roadside Beacons - A system using infrared or radio waves to communicate between transceivers placed at roadsides and the in-vehicle transceivers for navigation and route guidance functions.

Sigma - See Standard Deviation.

Spherical Error Probable (SEP) - The radius of a sphere within which there is a 50 percent probability of locating a point or being located. SEP is the three-dimensional analogue of CEP.

Standard Deviation (sigma) - A measure of the dispersion of random errors about the mean value. If a large number of measurements or observations of the same quantity are made, the standard deviation is the square root of the sum of the squares of deviations from the mean value divided by the number of observations less one.

Supplemental Air Navigation System - An approved navigation system that can be used in controlled airspace of the National Airspace System in conjunction with a primary means of navigation.

Surveillance - The observation of an area or space for the purpose of determining the position and movements of craft or vehicles in that area or space.

Survey - The act of making measurements to determine the relative position of points on, above, or beneath the Earth's surface.

Surveying - That branch of applied mathematics which teaches the art of determining accurately the area of any part of the Earth's surface, the lengths and directions of the bounding lines, the contour of the surface, etc., and accurately delineating the whole on a map or chart for a specified datum.

Terminal - A phase of navigation covering operations required to initiate or terminate a planned mission or function at appropriate facilities. For airborne missions, the terminal phase is used to describe airspace in which approach control service or airport traffic control service is provided.

Terminal Area - A general term used to describe airspace in which approach control service or airport traffic control service is provided.

Theta - Bearing or direction to a fixed point to define a line of position.

Time Interval - The duration of a segment of time without reference to where the time interval begins or ends.

TOPEX/POSEIDON - Topographic EXperiment/POSEIDON mission, a joint U.S./French oceanic mapping mission launched in August 1992.

Universal Transverse Mercator (UTM) Grid - A military grid system based on the Transverse Mercator projection applied to maps of the Earth's surface extending to 84^{o}N and 80^{o}S latitudes.

Vehicle Location Monitoring - A service provided to maintain the orderly and safe movement of platforms or vehicles. It encompasses the systematic observation of airspace, surface and subsurface areas by electronic, visual or other means to locate, identify, and control the movement of platforms or vehicles.

World Geodetic System (WGS) - A consistent set of parameters describing the size and shape of the Earth, the positions of a network of points with respect to the center of mass of the Earth, transformations from major geodetic datums, and the potential of the Earth (usually in terms of harmonic coefficients).

Appendix D

Glossary

The following is a listing of abbreviations for organization names and technical terms used in this plan:

AAA	American Automobile Association
AC	Advisory Circular
ADAM	Airport Datum Monument Program
ADF	Automatic Direction Finder
ADS	Automatic Dependent Surveillance
ADVANCE	Advanced Driver and Vehicle Advisory Navigation Concept
AFFSA	Air Force Flight Standards Agency
AFSPACECOM	Air Force Space Command
AGL	Above Ground Level
AIRSAR	Airborne Synthetic Aperture Radar
APTS	Advanced Public Transportation System
ARPA	Automatic Radar Plotting Aid
ARQ	Automatic Request/Reply
ARTCC	Air Route Traffic Control Center
ARTS	Advanced Rural Transportation System

ASOS	Automated Surface Observing System
ATC	Air Traffic Control
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
ATMSMN	Air Traffic Management System Material Need
AVC	Automatic Vehicle Classification
AVCS	Advanced Vehicle Control System
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
AVM	Automatic Vehicle Monitoring
AWN	Automatic Weather Network
AWOS	Automated Weather Observing System
BTS	Bureau of Transportation Statistics
C/A	Coarse/Acquisition
CCW	Coded Continuous Wave
CCZ	Coastal Confluence Zone
CDI	Course Deviation Indicator
CEP	Circular Error Probable
CGS	Civil GPS Service
CIA	Central Intelligence Agency
CIS	Commonwealth of Independent States
CJCS	Chairman, Joint Chiefs of Staff
cm	Centimeter
CNI/NAV	Communications, Navigation & Identification/ Navigation
CNS	Communication, Navigation and Surveillance

CNS/ATM	Communication, Navigation and Surveillance/Air Traffic Maintenance
CONUS	Continental United States
CORS	Continuously Operated Reference Sites
CS	Control Segment
CSE	Course Selection Error
CVO	Commercial Vehicle Operations
CW	Continuous Wave
DART	Dallas Rapid Transit District
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DH	Decision Height
DIA	Defense Intelligence Agency
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment
DME/P	Precision Distance Measuring Equipment
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOP	Dilution of Precision
DOS	Department of State
DOT	Department of Transportation
DR	Dead Reckoning
drms	Distance Root Mean Squared
DSARC	Defense System Acquisition Review Council
DSN	Deep Space Network

DT&E	Development Test & Evaluation
ECBF	Earth Centered Body Fixed
ECCM	Electronic Counter-Countermeasures
ECD	Envelope-to-Cycle Discrepancy
ECDIS	Electronic Chart Display Information System
ECEF	Earth Centered Earth Fixed
EHF	Extremely High Frequency
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EOS	Earth Observing System
EUVE	Extreme Ultraviolet Explorer
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
FAF	Final Approach Fix
FANS	Future Air Navigation System
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FGDC	Federal Geographic Data Committee
FHWA	Federal Highway Administration
FL	Flight Level
FLIP	Flight Information Publication
FM	Frequency Modulation
FMS	Flight Management System
FOC	Full Operational Capability
FRA	Federal Railroad Administration
FRP	Federal Radionavigation Plan
FSD	Full-Scale Development

FSS	Flight Service Station
FTA	Federal Transit Authority
FTE	Flight Technical Error
FTMI	Flight Operations and Air Traffic Management Integration
GA	General Aviation
GBF/DIME	Geographic Base File/Dual Independent Map Encoding
GCA	Ground Control Approach
GDOP	Geometric Dilution of Precision
GE0	Geostationary Earth Orbit
GES	Ground Earth Station
GHz	Gigahertz
GIB	GPS Integrity Broadcast
GLONASS	Global Navigation Satellite System (CIS system)
GM	General Motors
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPSIC	GPS Information Center
GSFC	Goddard Space Flight Center
GSTDN	Ground Satellite Tracking and Data Network
HAT	Height Above Touchdown
HDOP	Horizontal Dilution of Precision
HF	High Frequency
HHA	Harbor/Harbor Approach
HHE	Harbor/Harbor Entrance Area
HOV	High-Occupancy Vehicle

HSI	Horizontal Situation Indicator
Hz	Hertz (cycles per second)
IALA	International Association of Lighthouse Authorities
IAP	Improved Accuracy Program
ICAO	International Civil Aviation Organization
ICNS	Integrated Communication, Navigation and Surveillance
IF	Intermediate Fix
IFR	Instrument Flight Rules
IGS	International GPS Service
ILS	Instrument Landing System
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
INS	Inertial Navigation System
IOC	Initial Operational Capability
IOD	Issue of Data
IOTC	International Omega Technical Commission
IOT&E	Initial Operational Test & Evaluation
IRAC	Interdepartment Radio Advisory Committee
IRAC/SPS	IRAC Spectrum Planning Subcommittee
IRAC/SSG	IRAC Space Systems Group
ISS	International Space Station
ITS	Intelligent Transportation Systems
ITS-JPO	Intelligent Transportation Systems Joint Program Office
ITU	International Telecommunications Union
IVS	International VLBI Satellite
JCS	Joint Chiefs of Staff

JPO	Joint Program Office
JTIDS	Joint Tactical Information Distribution System
JTMLS	Joint Tactical Microwave Landing System
kHz	Kilohertz
km	Kilometer
LADGPS	Local Area Differential GPS
LF	Low Frequency
LOFF	Loran Flight Following
LOP	Line of Position
Loran	Long-Range Navigation
MAP	Missed Approach Point
MARAD	Maritime Administration
MASPS	Minimum Aviation System Performance Standards
MEP	Midcontinent Expansion Plan
MCS	Master Control Station
MCW	Modulated Carrier Wave
MDA	Minimum Descent Altitude
MF	Medium Frequency
MHz	Megahertz
MIJI	Meaconing, Interference, Jamming, and Intrusion
MLS	Microwave Landing System
mm	Millimeters
MNP	Master Navigation Plan
MNPS	Minimum Navigational Performance Specifications
MOA	Memorandum of Agreement
MOPS	Minimum Operational Performance Standard
MPA/TAC	Maritime Patrol Aircraft/Tactical Support Center

MSK	Minimum Shift Keying
MSS	Mobile Satellite Service
MTA	Mass Transit Administration
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NAD	North American Datum
NAG	Naval Astronautics Group
NANU	Notice Advisories to Navstar Users
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASA0	National Association of State Aviation Officials
NASPALS	NAS Precision Approach and Landing System
NATCOM	National Communications Center
NATO	North Atlantic Treaty Organization
NAVCEN	U.S. Coast Guard Navigation Center
NAVD	North American Vertical Datum
NCA	National Command Authority
NCD	Nautical Charting Division
NDB	Nondirectional Beacon
NGS	National Geodetic Survey
NGVD	National Geodetic Vertical Datum
NHTSA	National Highway Traffic Safety Administration
nm	Nautical Mile
NNSS	Navy Navigation Satellite System (Transit)
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NOTAM	Notice to Airmen

NPA	Nonprecision Approach
NPN	National Plan for Navigation
ns	Nanosecond
NSF	National Science Foundation
NSWC	Naval Surface Weapons Center
NTIA	National Telecommunications and Information Administration
O&M	Operation & Maintenance
OAB	Operational Advisory Broadcast
OASD/$C^3$1	Office of the Assistant Secretary of Defense for Command, Control, Communications and Intelligence
O C	Obstruction Clearance
O C S	Operational Control Segment
OCST	Office of Commercial Space Transportation
OMB	Office of Management and Budget
Omega	Ground-based VLF Navigation System (not an acronym)
ONSCEN	Omega Navigation System Center
OPS/QTV	Operations/Qualification Test Vehicle
OSD	Office of the Secretary of Defense
OST/ B	Assistant Secretary for Budget Programs
OST/C	General Counsel's Off ice
OST/M	Assistant Secretary for Administration
OST/P	Assistant Secretary for Transportation Policy
OTP	Office of Telecommunications Policy
P-code	Pseudorandom Tracking Code
PAR	Precision Approach Radar
PDOP	Position Dilution of Precision

POS/NAV	Positioning and Navigation
PPS	Precise Positioning Service
PPSPO	Precise Positioning Service Program Office
PRC	Pseudorange Corrections
PRN	Pseudo-Random Noise
PSE	Peculiar Support Equipment
PTTI	Precise Time-Time Interval
PWSA	Ports and Waterways Safety Act
RACON	Radar Transponder Beacon
RAIM	Receiver Autonomous Integrity Monitoring
RBN	Radiobeacon
R&D	Research & Development
RD&D	Research, Development & Demonstration
RDF	Radio Direction Finder
RDSS	Radiodetermination Satellite Service
R&E	Research & Engineering
R,E&D	Research, Engineering & Development
RF	Radio Frequency
RFI	Radio Frequency Interference
RNAV	Area Navigation
RNP	Required Navigation Performance
RRC	Range-Rate Corrections
RSPA	Research and Special Programs Administration
RSS	Root Sum Square
RTA	Required Time-of-Arrival
RTCM	Radio Technical Commission for Maritime Services
RTD	Rapid Transit District

RVP	Reference Vertical Profile
RVPT	Reference Vertical Profile with Time
RVR	Runway Visual Range
SA	Selective Availability
SAM	System Area Monitor
SAFI	Semi-Automatic Flight Inspection
SAR	Search and Rescue
SARPS	Standards and Recommended Practices
SC	Special Committee
SCAT I	Special Category I
SEP	Spherical Error Probable
SHF	Super High Frequency
SLSDC	Saint Lawrence Seaway Development Corporation
SOFIA	Stratospheric Observatory For Infrared Astronomy
SOPS	Space Operation Squadron
SPS	Standard Positioning Service
ST	Supplemental Type Certification
STOL	Short Take-Off and Landing
STS	Satellite Test System
S V	Space Vehicle
TACAN	Tactical Air Navigation
TC	Type Certification
TCV	Terminal Configured Vehicle
TD	Time Difference
TDRSS	Tracking and Data Relay Satellite System
TDSS	Time Difference Survey System
TERPS	Terminal Instrument Procedures

TIP	Transit Improvement Program
TIWG	Test Integration Working Group
TMC	Traffic Management Center
TOA	Time of Arrival
TOC	Traffic Operations Center
TONS	TDRSS Onboard Navigation System
TOT	Time of Transmission
Transit	Satellite-based Navigation System (not an acronym)
TravTe k	Travel Technology
TRSB	Time Referenced Scanning Beam
TSO	Technical Standard Order
TT&C	Telemetry Tracking and Control
TVOR	Terminal VOR
UE	User Equipment
UHF	Ultra High Frequency
URE	User Range Error
USAF	United States Air Force
U.S.C.	United States Code
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USD/A&T	Under Secretary of Defense for Acquisition and Technology
USGS	United States Geological Survey
USN0	United States Naval Observatory
USNOF	US NOTAM Office at FAA Headquarters
UTC	Coordinated Universal Time
VFR	Visual Flight Rules

VHF	Very High Frequency
VLBI	Very Long Baseline Interferometry
VLF	Very Low Frequency
VMS	Variable Message Sign
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range
VORTAC	Collocated VOR and TACAN
VSOPVLBI	Space Observatory Program
VTOL	Vertical Take-Off and Landing
VTS	Vessel Traffic Services
WAAS	Wide Area Augmentation System
WADGPS	Wide Area Differential GPS
WGS	World Geodetic System
WRC	World Radio Conference
WIM	Weigh-in-Motion
WMS	Wide Area Master Stations
WRS	Wide Area Reference Stations

1994 FRP Subject Index

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M

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O

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R

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T

V

W